DOCUMENT RESUME

ED 210 192

SE 035 952

AUTHOR	Gabel, Dorothy L.
TITLE	Facilitating Problem Solving in High School Chemistry.
INSTITUTION	Indiana Univ., Bloomington. School of Education.
SPONS AGENCY	National Science Foundation, Washington, D.C.
REPORT NO	NSF-RISE-SED-79-20744
PUB DATE	20 Feb 81
NOTE	680p.: For related document, see ED 202 671. Not available in paper copy due to marginal legibility of original document. Pages 456-462 removed due to copyright restrictions.
EDRS PRICE	MF04 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	*Aptitude Treatment Interaction; *Chemistry; Cognitive Processes; High Schools; High School Students; *Interviews; *Problem Solving; Science Education; *Science Instruction; Scientific Concepts; Secondary School Science; *Teaching Methods
IDENTIFIERS	*Science Education Research

ABSTRACT

The major purpose of this study was to determine whether certain types of instructional strategies (factor-label method, use of analogies, use of diagrams, and proportionality) were superior to others in teaching problem solving in four topics (mole concept, gas laws, stoichiometry, and molarity). Also of major interest was whether particular strategies would be more effective for students having different verbal-visual preferences, different levels of mathematics anxiety, and varying proportional reasoning ability. The design was a posttest only control group design. Subjects were 421 high school students drawn from 10 schools which ranged from rural/small town to metropolitan settings. Among other things, it was found that students of high mathematics anxiety scored significantly lower than did students of low mathematics anxiety, and that students of high proportional reasoning ability scored higher than did students of low ability. Findings related to the aptitude by treatment interaction indicate that students with high mathematics anxiety and an absence of another aptitude (visual preference or proportional reasoning ability) profited by instructional methods that contained supportive material that was not mathematical in nature. In a series of followup interviews, it was determined, among other findings, that students who did not understand the chemistry concepts were unsuccessful in problem solving and that students who were more successful used more organizing skills and used mneumonic notation. (SH)

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Facilitating Problem Solving in High School Chemistry

Dorothy L. Gabel
Indiana University
NSF Technical Report
RISE SED79-20744

SE 035 952

FACILITATING PROBLEM SOLVING
IN HIGH SCHOOL CHEMISTRY

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Bloomington, IN 47405

NSF Technical Report
RISE SED79-20744

February 20, 1981

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One of the basic skills required of high school chemistry students is problem solving. Students frequently lack proficiency in this area yet little research has been conducted that examines strategies that might be used to improve students' problem solving skills. An even more basic area that has not been investigated is the identification and synthesis of those processes students use in solving chemistry problems.

This project contained two major components. The first centered on instructional strategies that can be used in teaching students to solve chemistry problems to determine their relative effectiveness for different areas of chemistry. The second consisted of recording and analyzing students' thought processes while solving various types of chemistry problems. Each of these components will be considered separately in this report.

APTITUDE BY TREATMENT INTERACTION STUDY

The major purpose for conducting this study was to determine whether certain types of instructional strategies were superior to others in teaching high school students' problem solving in four topics integral to every chemistry course. These topics were the mole concept, the gas laws, stoichiometry, and molarity. In all four areas, the problems require similar algebraic and proportional reasoning skills. Also of major interest was whether particular strategies would be more effective for students having different verbal-visual preferences, different levels of mathematics anxiety, and varying proportional reasoning ability.

Background Information

Instructional Strategies

The effectiveness of four instructional strategies that are commonly used in high school chemistry courses was compared. These were: the factor-label method, the use of analogies, the use of diagrams, and proportionality.

The use of these four strategies can be seen in relation to the summary of memory structures and learning outcomes presented by Gagne and White (1978). They posulated that four memory structures lead to knowledge stating and rule application as shown in Figure 1. In this research, rule application is of particular interest because it is made manifest in the problem solving ability of the students.

Of the four types of memory structures postulated by Gagne and White, two are directly related to the instructional strategies employed in this study. The memory structure entitled "images" is of particular importance because two of the teaching strategies used as treatments present to the student images that may aid his/her problem solving skills (rule application). These strategies are the use of analogies in which chemical species are compared to physical objects, and the use of diagrams that represent the steps in problem-solving processes. The other two strategies, the factor-label method and proportionality, are related to the memory structure called intellectual skills. These two methods attempt to instill in the student systemmatic procedures for problem solving. Once acquired by the student, each could be called an intellectual skill.

The major difference in the four strategies is that in the first two cases, emphasis is placed on the student's image forming capability. The student can then use this in conjunction with the intellectual skills that he formulates and that are not stressed in the instructional units. In the latter two cases, the acquisition of the intellectual skill is directly taught but without the aid of imaginal adjuncts.

Verbal-Visual Preference

As mentioned in the previous section, two of the instructional strategies involved the use of images. The work of Paivio (1969, 1971) has been the basis

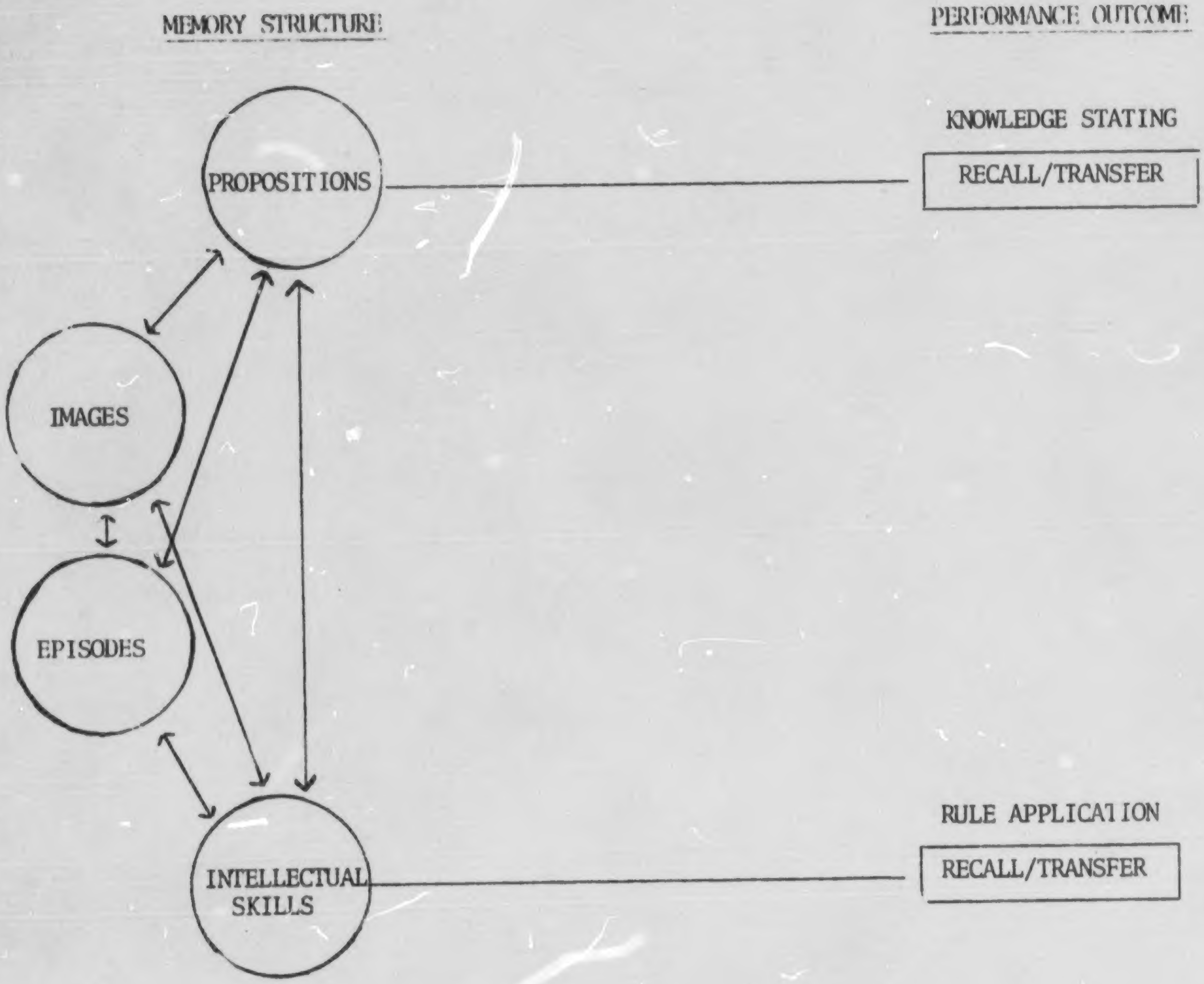
MEMORY STRUCTURE
PERFORMANCE OUTCOME
PROPOSITIONS
IMAGES
EPISODES
INTELLECTUAL SKILLS
KNOWLEDGE STATING
RECALL/TRANSFER
RULE APPLICATION
RECALL/TRANSFER

Figure 1. Memory structures and learning outcomes. (Modified from Gagne and White, 1978)

for much of the renewed interest in mental imagery. In his review article (1969) and in his book (1971) he has shown that the imagery envoking ability of nouns was separate from the previously used idea of meaningfulness. His theory classifies nouns as either being 'abstract' (lacking in imagery envoking ability) or 'concrete' (high in imagery envoking ability). He posulates a dual coding model hypothesis of independent verbal and imaginal memory coding structures. His later experiments with Csapo (1973) tended to support his dual coding hypothesis.

Other theorists have discussed imagery to some extent. Bruner et al. (1966) tends to view imagery (iconic representation) as a more primitive state of thought than verbal processes (symbolic representation). In their view, the imagery function diminishes as the verbal processes stabilize (age 7-8). Piaget (Piaget and Inhelder, 1971) takes a view more along the lines of Paivio's dual coding model. While Piaget suggests that the imagery ability of children goes through stages in somewhat a similar fashion to verbal ability, he indicates both modes of representation are available and used depending on the learning situation. Work by Forisha (1975) in which she measured the relationship between imagery ability and verbal ability and its change with age tended to support Piaget/Paivio theory of independent abilities instead of the Bruner theory.

The recent ACT model of cognition developed by Anderson (1976) tends to take a more propositional view of the representation of knowledge. While he states his model does not completely refute the dual coding hypothesis of Paivio he indicates that many of the results that have been found to support the dual coding hypothesis may be explained by a propositional network representation (p. 23, 394, 404).

A slightly different approach to the theory of cognition is taken by Munro and Rigney (1977). Their model, labeled schema theory, is less centralized than the Anderson model and allow the flow of processing control to be determined by the interactions among the conceptual entities (schemata) that make up the model.

Imagery could be considered to be interactions among schemata at a deep level of processing.

Several studies by Holliday and his associates have looked at comparisons of imagery and verbal instructional strategies in science instruction. In three studies by Holliday (1975, 1976a,b) the results point towards the superiority of a dual presentation of verbal plus diagram techniques versus strictly verbal presentations. Other studies by Holliday and Harvey (1976) and Holliday, Brunner and Donais (1977) tend to support the dual coding model although ordinal interactions with verbal ability in some studies (Holliday, 1976; Holliday, Brunner and Donais, 1977) made direct interpretation difficult.

Earlier work by Weisberg (1970), Dwyer (1972), and Arnold and Dwyer (1975) also tends to support the claim that both adults and children learn scientific concepts better when pictures or images are presented. As with the previous studies, however, these experiments did not deal with problem solving.

Studies in which problem solving was the instruction being undertaken are less common in the literature. Ernest (1977), in her imagery review article, denotes only one page of thirty-five to the topic on imagery and problem solving.

Early work by Frandsen and Holder (1969) used a spatial relations test as the measure of imagery and then developed instruction for experimental versus noninstructional control groups. Significant gains were made by the instructed group over the control group, but only for low spatial ability students.

Dreistadt's (1969) use of 'visual pictorial analogies' produced significant results for students who had the analogies as compared to the control group. This is consistent with the results of Atkinson's (1975, Atkinson and Raugh, 1975) work with analogies and second language learning. Although the analogies used by Atkinson were not visual they were of a nature such that students using them usually produced an image of the foreign word in a visual situation. Atkinson uses the example (1975) of the Spanish work for duck pato (pronounced "pot-o"). The English 'keyword' is pot and the student is encouraged to visualize a duck with a pot on its head. Strong results have been shown for this 'keyword' technique for both Spanish and Russian vocabulary.

Other studies in which an imagery component has seemed to make a difference are Shaver, Pierson, and Lang's (1974) work on syllogistic reasoning problems and their relationship to imagery and the computer-generated graphics experiments of Rigney and Lutz (1976). Shaver et al. showed that spatial type problems resulted in fewer errors and Rigney and Lutz's experiments indicated that verbal-graphical instruction was superior to verbal instruction on a chemistry concept.

In summary, the literature indicates that the use of techniques that allow mental imagery as an alternate method of coding are superior to strictly verbal techniques for many students. However, neither the dual coding hypothesis or the propositional network theories can completely explain all results.

Mathematics Anxiety

In the past few years there has been increased interest in mathematics anxiety. Auslander(1977); Blum (1977), Mitzman (1976), Sells (1978) and Tobias (1974) have shown that persons suffer from anxiety that is stimulated when they are in mathematical problem solving situations.

The relationship between mathematics anxiety and science achievement has been investigated for subject areas other than chemistry. Barnes (1977) has shown that mathematics anxiety is a predictor of semester grades for lower division college physics students. Sherwood and Gabel (1980) found that it was a weak predictor of success in a basic science skill course for preservice elementary teachers. Because success in chemistry involves being able to solve mathematical problems, it is likely that mathematics anxiety and success in chemistry are positively correlated.

Proportional Reasoning Ability

Examination of the problems involved in chemistry shows that the great majority of them require students to use proportional reasoning (Wheeler and Kass, 1977). Chemistry students, however, find these kinds of problems most difficult to solve. Data obtained in the study by Gabel and Sherwood, (1979) showed that not only the questions the students found most difficult were 56% problems, but that every problem involved proportional thinking. This finding, however, comes as no surprise because proportional reasoning according to Piaget (Inhelder and Piaget, 1958) is the most primary schema that characterizes the formal operational stage of development. Yet recent evidence indicates that at least 50% of high school students do not operate on the formal operational level (Chiapetta, 1976; DeCarcer, et.al., 1979; Karplus and Peterson, 1970; Lawson and Renner, 1974; Lovell, 1961; Lunger, 1965; Wollman and Karplus, 1974).

In the past few years there has been an increased interest by science educators in examining more closely reasons why students have difficulty using the proportionality schema (Karplus, Karplus and Wollman, 1974; Wheeler and Kass, 1977) and in devising training programs that are effective in teaching the schema (Kurtz and Karplus, 1979; Wollman and Lawson, 1978). In the latter two studies favorable results were obtained with seventh graders and prealgebra ninth and tenth graders, but the improvements were made in relation to mathematics, not proportionality as applied to science.

The most comprehensive study of chemistry and proportionality has been reported by Wheeler and Kass (1977). They found that success in chemistry (particularly problem-solving) was dependent on students proportional reasoning ability and that frequently students used an additive approach to solving chemistry problems. In the conclusions of this study they suggested, as did Herron (1975), that the use of the factor-label method may aid students in overcoming this proportionality handicap in problem solving.

This study tested not only the effectiveness of the factor-label method for use in problem solving but three other methods as well. The two more visual approaches (analogies and diagrams) might be considered more concrete than the verbal approaches and may be more effective for concrete learners (students with low proportional reasoning ability). Although recent studies have shown that concrete methods of instruction enhance science achievement in general for both formal and concrete students (Gabel and Sherwood, 1980a,b; Gerson & Primrose, 1977; Goodstein and Howe, 1978; Renner and Paske, 1977; and Sheehan, 1970), specific application to problem solving in chemistry has not been addressed, and differential results are feasible.

The fourth method for teaching problem solving was using proportionality. On the surface it would apprear that this method would be most positively correlated with students' proportional reasoning ability.

Questions Studied in the Aptitude X Treatment Interaction Study

The following questions were addressed in this study:

1. Are there differences in chemistry problem solving ability as measured by scores on immediate and delayed posttests for the selected topics and on a final examination according to students' proportional reasoning ability?

2. Are there differences in chemistry problem solving ability as measured by scores on immediate and delayed posttests for the selected topics and on a final examination according to students' verbal-visual preference?

3. Are there differences in chemistry problem solving ability as measured by scores on immediate and delayed posttests for the selected topics and on a final examination according to students' level of mathematics anxiety?

4. Are there differences in chemistry problem solving ability as measured by scores on immediate and delayed posttests for the selected topics and on a final examination according to the teaching strategy employed?

5. Are there any interaction effects between the teaching strategy employed, students verbal-visual preference, students' mathematics anxiety level and students' proportional reasoning ability that result in differences in chemistry

problem solving ability as measured by scores on immediate and delayed posttests on each of the four topics and on a final examination?

6. Are there any differences in chemistry problem solving ability as measured by scores on the sum of transfer items of the posttests according to teaching strategy employed, students' verbal-visual preference, students' mathematics anxiety level, and students' proportional reasoning level.

7. Are there any differences in chemistry problem solving ability when the problems contain decimals, according to teaching strategy employed, students' verbal-visual preferences, students' mathematics anxiety level, and students' proportional reasoning level?

8. Are there any differences in chemistry problem solving ability as measured by the ACS-NSTA Chemistry Achievement Test according to the amount of notation students used in solving the problem?

9. Do students who solve a chemistry problem taught by different strategies vary in amount of the notation they use to solve the problem?

10. Are there any differences in the amount of time spent in completing a lesson on the gas laws or molarity where the teaching strategy is mismatched with the students' verbal-visual aptitude versus when it is matched?

11. Are there any differences in the time spent in completing a lesson on the gas laws or molarity when the teaching strategy is mismatched with the students' proportional reasoning ability?

Methods and Procedures

Experimental Design

The design used for this Aptitude by Treatment Interaction experiment was basically a "Posttest only Control Group Design" described by Campbell and Stanley (1963, p.25). Figure 2 summarizes the design.

Sample

The minimum number of subjects that Cronbach and Snow (1977, p.46) recommended

A R W_1O_1 W_2O_2 W_3O_3 W_4O_4 O_5 X_1O_1 X_2O_2 X_3O_3 O_5 Y_1O_1 Y_2O_2 Y_3O_3 O_5 Z_1O_1 Z_2O_2 Z_3O_3 O_5 O_6

A R W_1O_1 W_2O_2 W_3O_3 W_4O_4 O_5 X_1O_1 X_2O_2 X_3O_3 O_5 Y_1O_1 Y_2O_2 Y_3O_3 O_5 Z_1O_1 Z_2O_2 Z_3O_3 O_5 O_6

A R W_1O_1 W_2O_2 W_3O_3 W_4O_4 O_5 X_1O_1 X_2O_2 X_3O_3 O_5 Y_1O_1 Y_2O_2 Y_3O_3 O_5 Z_1O_1 Z_2O_2 Z_3O_3 O_5 O_6

A R W_1O_1 W_2O_2 W_3O_3 W_4O_4 O_5 X_1O_1 X_2O_2 X_3O_3 O_5 Y_1O_1 Y_2O_2 Y_3O_3 O_5 Z_1O_1 Z_2O_2 Z_3O_3 O_5 O_6

Where: A = Aptitude measures (proportional reasoning test, mathematics anxiety test, and verbal-visual preference).

R = Random assignment of subjects to treatments.

WXYZ = The instructional treatments on the four chemistry topics (moles, gas laws, stoichiometry, and molarity. Subscripts indicate the four treatments, factor-label, analogies, diagrams, and proportionality).

O_1-O_4 = Immediate posttests given after each lesson. These scores were summed for the analysis.

O_5 = Delayed posttests.

O_6 = ACS-NSTA Examination in High School Chemistry.

Figure 2. Summary of design for aptitude x treatment interaction study.

for aptitude by treatment interaction studies is 100 per treatment. Permission was obtained from ten teachers and their school corporation/principals in eight school corporations in central and southern Indiana to participate in the experiment. The school systems involved included a wide range of school types, i.e., rural/small towns, moderate size cities, suburban and inner city. Three schools could be considered to be rural/small town high schools (school population 1000 or less). These three schools represented approximately 24% of the total sample. Three schools were from moderate size cities (school population 1200-1800). These represented approximately 50% of the sample. One school was in a suburb of a major metropolitan area (school population approximately 1400). This school represented approximately 16% of the sample. The final school was an inner city school from the same metropolitan area as the previous school (school population over 2000). This school represented 10% of the sample.

From these schools, 609 students in first year chemistry classes were administered the aptitude measures. Due to schedule changes, absences, and missing data, 421 students completed the entire experiment. Individual permission from the student and/or parent was obtained before the commencement of the treatments. Copies of principal/school corporation forms, student permission forms, and Human Subjects Summary Safeguard Statements are included in Appendix A.

In addition to obtaining written consent from each school, the principal investigator had a conference with the principal in each of the eight schools. Its purpose was to describe the objectives of the experiment and clarify procedures that would be used.

Measurement of Verbal-Visual Preference

Students' verbal-visual preference was measured by a modification of the Paivio Individual Differences Questionnaire (IDQ). A factor analytic study recently reported by Paivio (1979) indicated a strong two factor solution for a

54 item subset (31 verbal, 23 imagery) of the 86 item questionnaire. Paivio's scoring method of producing a verbal and an imagery score for each person was followed. Because the instrument utilizes a true-false format, subjects were given one point of their verbal score when they agreed with the scoring key on a verbal item and one point on their imagery score for agreement. Items which did not agree were ignored.

While no direct measurement of reliability was reported by Paivio in the original development (1971, p. 495) or in the recent factor analytic study (1979), a shortened form (15 items) used by Richardson (1977) had a reliability of 0.93 using the test-retest method. Paivio did report a correlation of greater than 0.9 between the 54 item instrument and the longer 86 item instrument. Alpha reliability based on our data of the verbal scale was found be to .84 and of the visual scale .73.

The paper and pencil format of the test allowed adiminstration in a relatively short time span (approximately 20 minutes). Items were coded directly on optical scan coding sheets. Appendix B contains the modified IDQ and directions for administration. Students were administered this instrument during the first three weeks of school in seven of the eight schools. (The inner city school was not in session due to a labor dispute and the administration was delayed until the end of the semester.)

Measurement of Mathematics Anxiety

The Mathematics Anxiety Rating Scale was used to measure students' mathematics anxiety. This instrument is a 98 item self-rating scale in which students are asked to describe their anxieties as they currently exist. Each item on the scale represents a situation that may arouse anxiety within the subject. The subject decides the degree of anxiety aroused and marks the corresponding amount (not at all, a little, a fair amount, much, or very much) on the instrument. In order to facilitate scoring, students marked answers directly on optical scanning sheets instead of on the copies of the instrument. A copy of the MARS which was developed by Suinn, is found in Appendix B.

Administration of the scale required approximately 20 minutes. Teachers selected their own preferred time of administration during the first semester. The alpha relability of the scale was found to be .97.

Measurement of Proportional Reasoning Ability

The proportional reasoning section of the Staver (1978) instrument offered a compromise between conducting Piagetian interviews with each student and administering a strictly paper and pencil instrument. The ideal situation would be to administer clinical interviews to the students. The number of subjects, however, did not make this approach practical. The video-tape format with a written response sheet was used in a modification of the Staver instrument. In order to increase the number of items, more tasks were added to the Staver instrument. These were the "two cylinder task" of Lawson's (1978) overall test of formal operations and the "disks task" developed by Wollman and Lawson (1978). The developers of these tasks indicated that they had strong content validity and the tasks were well suited to a video-tape presentation. Bady (1978) has indicated that multiple tasks are needed for Piagetian task tests.

Staver (1978) included both reasoning tasks (Mr. Short-Mr. Tall and the Balance Beam) for a total of eleven questions. The addition of the two tasks allowed for ten additional numerical and reasoning questions making a total of 21 questions. The coefficient alpha reliability estimate was .85.

Administration time for the instrument was approximately 30 minutes. Appendix B contains the written portion of the instrument and administration instructions. The test was administered during the same day that the verbal-visual questionnaire was given.

Measurement of Problem Solving Ability

Problem solving ability was measured in five different ways. These were by immediate posttests, delayed posttests, the ACS-NSTA Chemistry Achievement Test, transfer items from the delayed posttests, and decimal items from the immediate posttests. Each will be discussed separately.

Immediate Posttests. Students' immediate ability to solve numerical chemistry problems for each unit of instruction was measured by their scores on short tests given afer each lesson within a given unit. Each of the four units (moles, gas laws, stoichiometry and molarity) contained three or four lessons that took one to two days to complete. When a student completed a lesson, he was administered a multiple choice test of 4 - 6 items that contained problems similar to those taught in the lesson. Although the test questions for each treatment were identical, a short reminder of the treatment technique was printed at the top of the first page of each test. This was done in order to encourage students to learn to solve the problems by the method presented in their own booklets and to discourage exchanging booklets with their friends.

Due to the short length of these tests, their proximity of administration, and their similar domain of instruction, scores from tests on individual lessons were summed to produce an immediate posttest score for each unit. The types of items on these immediate posttest were similar for all units in that two of the items on each of the tests were always the same in content but differed in that one problem presented data in decimals whereas the other did not.

All of the test items were critiqued by a chemist and two chemistry educators (not associated with the development) for accuracy and appropriateness for the unit. The chemical educator reviewers' comments are found in Appendix C Copies of the tests are found in Appendix D and in Appendix N inserted after each instructional unit. An item analysis is found in Appendix D. Table 1 gives the reliability and composition of each of the unit posttests.

Delayed Posttests. Within two weeks after completing all lessons in a given unit, teachers administered the delayed posttests for each unit. This was a ten item multiple choice test that contained problems similar to those taught in the unit and in the immediate posttests. These items were also scrutinized by a chemist and chemistry educator.

On every test at least one transfer item was included. This was a problem that had never been presented in the instructional unit but the student should have been able to answer if he understood the material that had been presented. Table 2 gives the reliability of the delayed posttests. Copies of the unit tests are found in Appendix D. They occur also at the end of each unit in Appendix N. Item analysis are contained in Appendix D. Reviewers' comments on test items appear in Appendix C.

ACS-NSTA Chemistry Achievement Test. The ACS-NSTA Cooperative Examination, High School Chemistry Form 1975, Part I was administered by classroom teachers during the final month of the school year after all four instructional units had been completed. In several schools both the regular and scrambled version of the test were given to eliminate the possibility of cheating. This test is commonly given in schools as a final examination and measures facts, concepts, and problem solving skills. Part I of the 1975 examination was selected because it contained the largest number of items that were related to the problems taught in the instructional units. It contains 40 items and has an administration time of 40 minutes. The alpha reliability of the regular form was found to be .75 (n = 410) and the scrambled form .55 (n = 146). Ten of the 40 items were directly related to problems taught in the units. Reliability on the regular and scrambled form for a subtest consisting of these items were .67 and .33 respectively. Non-problem items had reliability of .74 and .37 respectively. Copies of the instrument

Table 1

Description and Reliability Coefficients

of Immediate Posttests

Unit	No. of Lessons	Total No. of Items	No. of Cases	Coefficient Alpha
Moles	4	21	498	.76
Gas Laws	3	12	496	.66
Stoichiometry	3	12	507	.73
Molarity	3	15	434	.75

Table 2

Description and Reliability Coefficients of Delayed Posttests

Units	Total No. of Items	Transfer Items	No. of Cases	Coefficient Alpha
Moles	10	4,9	498	.69
Gas Laws	10	3,6,10	496	.73
Stoichiometry	10	5,9	507	.81
Molarity	10	5,7,10	434	.71

are not given in the Appendix because of the confidential nature of the test but are available from the Examination Committee - ACS. An item analysis of each form of the instrument is found in Appendix D.

As a check to see if students were using the strategy taught (factor-label, etc.) to solve the problems and also to examine their use of using units (mneumonic notation) students were asked to show their work for problem 12 (problem 29 on the scrambled version), a stoichiometry problem. Their responses were then coded as to whether students used the strategy taught and the degree of using notation (none, minimal, complete). Agreement of two raters on a sample of the responses (n = 33) was 87.8%.

Transfer Items Test. Inserted in each of the delayed posttests was at least one transfer item. As mentioned previously, these items consisted of problems that were not directly taught in the instructional units. The units did contain enough information so that if students understood the concepts they should have been able to work the problems. As an independent check to verify that these items were truly transfer items, the tests and instructional units were sent to two chemistry educators. They were asked to identify any transfer items given in the tests. Agreement of one science educator was 90%. Agreement of the other was 80%. At least one of the two outside evaluators agreed with each item included as transfer items.

The ten transfer items from the four posttests were grouped together and treated as an additional dependent measure. The alpha reliability of this sub-test was found to be .48 (n = 434). The non-transfer items (30) had a reliability of .81 (n =435).

Decimal Items. One of the reasons students may have difficulty in solving chemistry problems is because of their inability to handle problems containing decimals. In order to test this hypothesis, the test following every lesson in each unit contained two problems that were identical in concept but differed in that one of the problems contained decimals and while the companion item contained whole numbers. These decimal items and their companion items formed two subtests across the four instructional units containing 13 items each. The alpha reliabilities of these subsets were .40 and .57 respectively (n = 421).

Packet Evaluation

At the end of the semester, students were asked to evaluate the instructional strategy and the materials that they used to learn to solve problems. Students answered anonymously on the particular strategy they used. Questions were also included to determine how much contamination there was between the treatments. The questionnaires used are found in Appendix E.

Evaluation According to Time

After a presentation of the progress of this project at an NSF director's meeting in March, 1980, a suggestion was made that a comparison of the length of time it took students to complete units might be of interest. Students whose aptitudes were in opposition to the strategy with which they were taught to solve problems might take longer to complete the units than students for whom these matched.

By the time plans could be made to implement these, many teachers had completed the units. It was possible to have two teachers ask students to recored the time spent to complete the gas law lessons and three teachers for molarity lessons. Students recorded the time when they began a lesson and the time at which they reached the supplementary practice problems. Some teachers also had students note whether they used a calculator to obtain the answers.

Instructional Treatments

During the fall semester of 1979-80 school year, the four instructional units according to each of the four teaching strategies were developed. Each unit consisted of a brief Teachers' Guide and Student Materials.

The Teachers' Guides (Appendix F) contain a list of prerequisite skills the students would need to have accomplished before beginning each lesson of the unit, the objectives of each lesson of the unit, and answers to the immediate posttests and to the delayed posttests.

Students' Guides contained three to four lessons each of which included an introduction, several self-programmed sections on the concepts to be learned, summary section with extra practice problems, and a sheet containing answers and solutions to the problems. These practice problems were not presented in the same order as the topics were introduced and were optional. The reason they were included was to try to control the amount of time students in each treatment spent studying the unit. If students finished the required material with extra time before the immediate posttest was to be administered they were directed to work on the extra practice problems. The Student Guides are found in Appendix N. Table 3 summarizes their content.

In addition to the Student Guide, students were given a Review Sheet that contained a brief summary of the method used to solve the problems and some sample problems. These were to be used to study for the Unit Tests because teachers had collected their Student Guides. Copies are found in Appendix C.

Development of the units was a very time-consuming process. After the first draft of each unit was completed, the units were scrutinized by a chemist for chemistry errors, clarity of wording and overall suitability. Units were then revised taking into account the suggestions for improvement.

A final critique of the units was made by two chemistry educators. Their comments are found in Appendix C . They were asked to make judgements about the reasonableness of the objectives, the adequateness of the prerequisite skills and coverage of the topics, the existence of chemistry errors and the matching of the instruction with the objectives. Chemistry errors discovered at this stage were sent to teachers via errata sheets.

Table 3

Instructional Units

Unit	Lesson	Title
Mole Concept	1	The Mole as Number
Mole Concept	2	The Mole as Volume
Mole Concept	3	The Mole as Mass
Mole Concept	4	Mass, Volume and Particles
Gas Laws	1	Volume and Pressure
Gas Laws	2	Volume and Temperature
Gas Laws	3	Volume, Temperature and Pressure
Stoichiometry	1	Relationships from Equations
Stoichiometry	2	Mass Relationships
Stoichiometry	3	Volume Relationships
Molarity	1	Definition of Molarity
Molarity	2	Diluting and Concentrating
Molarity	3	Acid-Base Reactions

Units were written using four different teaching strategies: the factor-label method, the use of analogies, the use of diagrams, and proportionality. Each method had some commonalities, but some major differences.

The focus of the factor-label method was on the importance of estimating methods to obtain correct answers by looking at the units of the given values. Students were shown how the units 'cancel out' in the calculations and how incorrect answers may be determined by looking at the units of the answer. A sample problem (from the mole as ideal gas volume unit) was: "If a sample O_2 gas had a volume of 89.6 liters at STP, how many moes would be represented?" The factor-label method would indicate to the student that they should set up their factor (1 mole = 22.4 liters) so that the liters will cancel:

$$89.6\ \cancel{\text{liters}}\ O_2 \times \frac{1\ \text{mole}}{22.4\ \cancel{\text{liters}}} = 4\ \text{moles}\ O_2$$

The analogy method used common examples to help students understand the relationship needed to solve the problem. Examples used both the common examples and chemical examples to work the problems. The gas law problems' analogy was that of a shipping carton of fruit. No matter what size the fruit was the volume for a dozen fruit was always 3 pints. The problem, "How many dozen of fruit would fit into a delivery box that had a volume of 54 pints?" was worked immediately before the 89.6 liters of O_2 problem was shown. Mathematically the analogy problems were identical to the diagram problems:

$$\frac{89.6\ \text{liters}\ O_2}{22.4\ \text{liters/mole}} = 4\ \text{moles}\ O_2$$

The diagrammatic method used the diagram (or sections of the diagram) pictured in Figure 3 . Students were shown that certain steps (boxes on the diagram) must be taken in order to reach the desired answer. In some situations (in which multiplication was used) the diagrammatic and factor-label methods

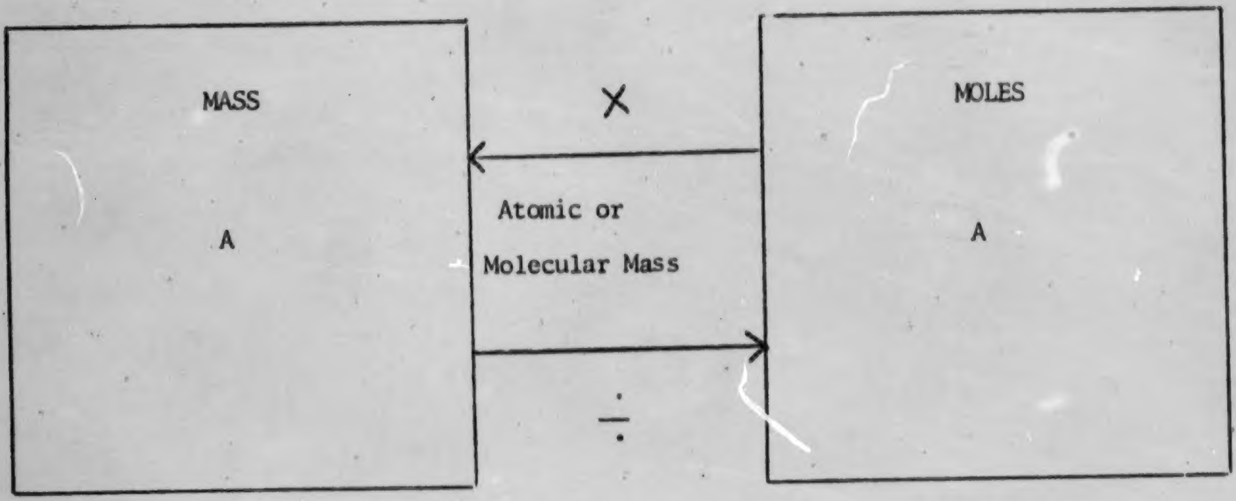
MASS
A
×
Atomic or
Molecular Mass
÷
MOLES
A

Figure 3. Schematic diagram for solving moles problems.

were very similar. When division was indicated by the diagram, however, they differed in that the factor-label method used multiplication by a reciprocal rather than division. The gas law problem would be set up as:

$$\frac{89.6 \text{ liters } O_2}{22.4 \text{ liters/mole}} = 4 \text{ moles } O_2$$

The proportionality method used techniques of the form $\frac{A}{B} = \frac{C}{X}$ to help the students determine the value of X. While the fact that the units 'cancel out' to yield reasonable units for the answer was discussed, this was not emphasized. For the gas volume problem, the students were shown that the problem could be solved by the use of a simple proportion:

$$\frac{X}{89.6 \text{ liters } O_2} = \frac{1 \text{ mole}}{22.4 \text{ liters}}$$

$$(X)\ (22.4 \text{ liters}) = (89.6 \text{ liters } O_2)\ (1 \text{ mole})$$

$$X = \frac{(89.6 \text{ liters } O_2)\ (1 \text{ mole})}{(22.4 \text{ liters})} = 4 \text{ moles } O_2$$

While all the methods had differences, the canceling of units was carried out in all four types.

The instructional units were administered by teachers in their classrooms. Prior to their administration, a meeting was held which eight of the ten teachers participating in the study attended. (One teacher had another commitment and the other was on strike. Procedures were explained to them individually.) The purpose of the meeting was to give the teachers an overview of the project, describe differences in instructional strategies and discuss procedures to be used and appropriate follow-up activities that would be suitable. Every effort was made to try to form a partnership with the teachers in doing the study.

The following procedures were agreed upon:

1. Students would be assigned randomly to treatments by each teacher

dividing each of his classes into four convenient groupings. He would label these groups one through four. The numbers one to four were then drawn from a lot at a later date and the teachers notified which instructional strategy corresponded to which number.

2. Each instructional strategy would be color coded to facilitate distribution of the same strategy to the same students across the four units (13 lessons). The color coding was a follows: factor-label = yellow, analogies = blue, diagram = green, and proportionality = pink Immediate posttests and review sheets were color coded in the same way.

3. Instructional units were to be used in the classroom. Individual lessons would be distributed at the beginning of the period. Students worked on these individually but they could consult other students using the same strategy (color) or could obtain help from their teacher. The lessons varied in length over the various topics and took between 40 minutes - two hours to complete. Because the length of periods varied greatly in the schools, in some cases students finished in one period whereas in others three periods were required. If students did not finish a lesson by the end of the class period, the booklets were collected and redistributed the next day. Booklets eventually were returned to the university.

4. Immediate posttests would be given when the students in the class were finished with the instructional booklets. All teachers permitted students to use hand calculators to work the problems. Tests were corrected by the teacher who then returned them to the investigator. Answers were then transferred to optical scanning sheets for data processing.

5. After students completed the lessons, the teachers in some instances desired to follow up these lessons with supplementary work. In these cases, teachers were asked to use the method of showing that the units cancel. This

was common to all four instructional strategies. Although there is no guarantee that teachers did this in every instance, every teacher was observed at least twice and some as many as four times while they were administering the units or taught their classes immediately following the units.

6. After all of the lessons in a given unit were completed (including the immediate posttests), teachers would give a review sheet to each student that corresponded to the instructional treatment assigned. The review sheet which contained a summary of the method and sample problems provided the student with a study guide to prepare for the delayed posttests that were to be administered within two weeks of completing the lessons. It was thought that these review sheets would encourage students to use the same method that they were taught in class but yet would be too sketchy to enable students to learn a completely different method than the one to which they were assigned. Teachers corrected the delayed posttests and sent the test sheets to the university where answers were transferred to optical scanning sheets.

The teachers' use of the units was monitored by visits to their classrooms during and after the use of the booklets. Discussions were also held with the teachers during data collection visits and by phone to determine if any instructional problems had occurred with the content of the units or with the administrational procedures. Some minor typographical errors were found and corrected. Overall, the instruction was applied as outlined in the previous sections.

Hypotheses

The dependent variables referred to in hypotheses 1 - 53 are as follows:

1. The immediate posttests (QT) for each of the four instructional treatments: moles (MO), gas laws (GL), stoichiometry (S), and molarity (ML).

2. The delayed posttests (T) for each of the four instructional treatments listed in 1.

3. The ACS-NSTA Chemistry Achievement Test (ACSTOT).

4. The ACS-NSTA Problem Subtest (ACSPROB) and Nonproblem Subtest (ACSNPROB).

5. The Transfer Test made of 10 items from the delayed posttests (TRANST) and the remaining items (NTRANST).

6. The Decimal Test made of 13 items from the immediate posttests (DECMILQ) and the equivalent items (NDECMILQ).

Hypotheses tested in this aptitude by interaction study are as follows:

1. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the aptitude of verbal or visual preference to the multiple linear regression equation.

2. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the aptitude of mathematics anxiety to the multiple regression equation with the variance due to verbal and visual preference removed.

3. There is no significant increase in the percentage of variance ac counted for in each dependent variable by the addition of the aptitude of proportional reasoning ability to the multiple linear regression equation with the variance due to verbal-visual preference and mathematics anxiety removed.

4. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of dummy variables coded for treatments, with the variance due to the three aptitude measures removed.

5. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of a dummy variable

coded for the factor-label treatment with the variance due to the three aptitude measures removed.

6. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of a dummy variable coded for the analogy treatment with the variance due to the aptitudes and previous treatment measures removed.

7. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of a dummy variable coded for the diagram treatment, with the variance due to the aptitudes and previous treatment measures removed.

8. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the combination of dummy variables coded for the proportionality treatment with the variance due to the aptitudes and previous treatments removed.

9. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the six variables representing the verbal or visual preference by treatments interaction with variance due to aptitudes and treatments removed.

If hypothesis nine is rejected, hypotheses ten through thirteen will be tested.

10. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference by factor-label treatment interaction with variance due to aptitudes and treatments removed.

11. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference by analogy treatment interaction

with variance due to aptitudes, treatments and verbal or visual preference by previous treatment interaction removed.

12. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference by diagrammatic treatment interaction with variance due to aptitudes, treatments and the other verbal or visual preference by treatment interactions removed.

13. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference by proportionality treatment interaction with variance due to aptitudes, treatments, and the other verbal or visual preference by treatment interactions removed.

14. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the three variables representing the mathematics anxiety score by treatments interaction with variance due to aptitudes, treatment, and verbal or visual preference by treatment interactions removed.

If hypothesis 14 is rejected, hypotheses 15 through 18 will be tested.

15. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the mathematics anxiety by factor-label treatment interaction with the variance due to aptitudes, treatments, and verbal or visual preference by treatment interactions and removed.

16. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the mathematics anxiety by analogy treatment interaction with variance due to aptitudes, treatments, verbal or visual preference by treatment interactions and the previous mathematics anxiety by treatment interactions

removed.

17. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the mathematics anxiety by diagrammatic treatment interaction with variance due to aptitudes, treatments, verbal or visual perference by treatment interactions, and mathematics anxiety by treatment interactions removed.

18. There is no significant increase in the percentage of variance accounted for in the dependent variable matrix by the addition of the variable representing the mathematics anxiety by proportionality treatment interaction with variance due to aptitudes, treatment, verbal or visual by treatment interaction and mathematics anxiety by treatment interactions removed.

19. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the three variables representing the proportional reasoning ability by treatments interaction with variance due to aptitudes, treatments, verbal-visual preference by treatment interactions and mathematics anxiety by treatment interactions removed.

If hypothesis 19 is rejected, hypotheses 20 through 23 will be tested.

20. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable accounted for in each dependent variable by the addition of the variable representing the proportional reasoning by the factor-label treatment interaction with the variance due to aptitudes, treatments, verbal or visual preference by treatment interactions and mathematics anxiety by treatment interactions removed.

21. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the proportional reasoning ability by analogy treatment interaction with variance due to aptitudes, treatments, verbal or visual by treatment interactions, mathematics anxiety by treatment interactions, and the previous proportional reasoning by factor-label treatment interaction removed.

22. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the proportional reasoning by the diagrammatic treatment interaction with variance due to aptitudes, treatments, verbal or visual by treatment interactions, mathematics anxiety by treatment interactions and previous proportional reasoning by treatment interactions removed.

23. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the proportional reasoning by proportionality treatment interaction with variance due to aptitudes treatments, verbal or visual by treatment interactions, mathematics anxiety by treatment interactions and proportional reasoning by treatment interactions removed.

24. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the three variables representing the verbal preference - visual preference by treatments interactions with the variance due to all previous aptitudes, treatments and interactions removed.

If hypothesis 24 is rejected, hypotheses 25 through 28 will be tested.

25. There is no significant increase in the percentage of variance

accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference by factor-label treatment interaction with the variance due to all previous aptitudes, treatments and interactions removed.

26. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference by analogy treatment interaction with the variance due to all previous aptitudes, treatments and interactions removed.

27. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference by diagrammatic treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

28. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference by proportionality treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

29. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the six variables representing the verbal or visual preference - mathematics anxiety by treatments interaction with the variance due to all previous aptitudes, treatments and interactions removed.

If hypothesis 29 is rejected, hypotheses 30 through 33 will be tested.

30. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal and visual preference - mathematics anxiety by

factor-label treatment interaction with the variance due to all previous aptitudes, treatments and interactions removed.

31. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal and visual preference - mathematics anxiety by analogy treatment interation with the variance due to all previous aptitudes, treatments, and interactions removed.

32. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal and visual preference - mathematics anxiety by diagrammatic treatment interaction with the variance due to all previous aptitudes, treatment, and interactions removed.

33. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal and visual preference - mathematics anxiety by proportionality treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

34. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the six variables representing the verbal or visual preference - proportional reasoning ability by treatments interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

If hypothesis 34 is rejected, hypotheses 35 through 38 will be tested.

35. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference - proportional reasoning ability by factor-label treatment interaction with the variance due to all previous

aptitudes, treatments, and interactions removed.

36. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference - proportional reasoning ability by analogy treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

37. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference - proportional reasoning ability by diagrammatic treatment interaction with the variance due to all previous aptitudes, treatments and interactions removed.

38. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference - proportional reasoning ability by proportionality treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

39. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the three variables representing the mathematics anxiety - proportional reasoning ability by treatments interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

If hypothesis 39 is rejected, hypotheses 40 through 43 will be tested.

40. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the mathematics anxiety - proportional reasoning ability by factor-label treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

41. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the mathematics anxiety - proportional reasoning ability by analogy treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

42. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the mathematics anxiety - proportional reasoning ability by diagrammatic treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

43. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the mathematics anxiety - proportional reasoning ability by proportionality treatment interaction with the variance due to all previous aptitudes, treatments, and interaction removed.

44. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the three variables representing the verbal preference - visual preference - mathematics anixety by treatments interactions with the variance due to all previous aptitudes, treatments, and interactions removed.

If hypothesis 44 is rejected, hypotheses 45 through 48 will be tested.

45. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - mathematics anxiety by factor-label treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

46. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - mathematics anxiety by analogy treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

47. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - mathematics anxiety by diagrammatic treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

48. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - mathematics anxiety by proportionality treatment interaction with the variance removed due to all previous aptitudes, treatments, and interactions removed.

49. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the three variables representing the verbal preference - visual preference - proportional reasoning ability by treatments interactions with the variance due to all previous aptitudes, treatments, interactions removed.

If hypothesis 49 is rejected, hypotheses 50 through 53 will be tested.

50. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - proportional reasoning ability by factor-label treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

51. There is no significant increase in the percentage of variance

accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - proportional reasoning ability by analogy treatment interaction with the variance due to all previous aptitudes treatments, and interactions removed.

52. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - proportional reasoning ability by diagrammatic treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

53. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - proportional reasoning ability by proportionality treatment interaction with the variance due to all previous aptitudes, treatments, and interactions removed.

54. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of six variables representing the verbal or visual preference - mathematics anxiety - proportional reasoning ability by treatments interactions with the variance due to all previous aptitudes, treatments, and interactions removed.

If hypothesis 54 is rejected, hypotheses 55 through 58 will be tested.

55. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference - mathematics anxiety - proportional reasoning ability by factor-label treatment interaction with variance due to all previous aptitudes, treatments and interactions removed.

56. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable

representing the verbal or visual preference - mathematics anxiety - proportional reasoning ability by analogy treatment interaction with variance due to all previous aptitudes, treatments and interactions removed.

57. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference - mathematics anxiety - proportional reasoning ability by diagrammatic treatment interaction with variance due to all previous aptitudes, treatments, and interactions removed.

58. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal or visual preference - mathematics anxiety - proportional reasoning ability by proportionality treatment interaction with variance due to all previous aptitudes, treatments, and interactions removed.

59. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of three variables representing the verbal preference - visual preference - mathematics anxiety - proportional reasoning ability by treatments interactions with the variance due to all previous aptitudes, treatments, and interactions removed.

If hypothesis 59 is rejected, hypotheses 60 through 63 will be tested.

60. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - mathematics anxiety - proportional reasoning ability by factor-label treatment interaction with variance due to all previous aptitudes, treatments, and interactions removed.

61. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable

representing the verbal preference - visual preference - mathematics anxiety - proportional reasoning ability by analogy treatment interaction with variance due to all previous aptitudes, treatments, and interactions removed.

62. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - mathematics anxiety - proportional reasoning ability by diagrammatic treatment interaction with variance due to all previous aptitudes, treatments, and interactions removed.

63. There is no significant increase in the percentage of variance accounted for in each dependent variable by the addition of the variable representing the verbal preference - visual preference - mathematics anxiety - proportional reasoning ability by proportionality treatment interaction with variance due to all previous aptitudes, treatments, and interactions removed.

64. There is no difference in achievement by chemistry students on problems that contain decimals as compared to equivalent problems that do not contain decimals.

65. There is no difference in achievement as measured by the ACS-NSTA Chemistry Achievement Test by chemistry students according to the amount of notation used in solving a specified problem.

66. There is no difference in the amount of notation used in solving a specified problem by chemistry students who solve problems when taught by different strategies.

67. There is no difference in the amount of time spent in completing lessons involving the gas laws or molarity by students whose verbal-visual aptitudes match the instructional strategy used in learning the lessons versus students whose aptitudes and strategies do not match.

68. There is no difference in the amount of time spent in completing lessons involving the gas laws or molarity by students whose proportional

reasoning ability matches the instructional strategy used in learning the lessons versus students whose aptitudes and strategies do not match.

In addition to the formal testing of these 68 hypotheses, a questionnaire was administered to students at the end of the school year to obtain their general reaction to the packets. The questionnaire contained nine questions that pertained to the usefulness of the materials and to whether there was any contamination of the treatments. Copies are found in Appendix E.

Statistical Analyses

Hypotheses 1 - 63 involved aptitude by treatment interactions that were analyzed using multiple linear regression techniques. As Cronbach and Snow (1977, p. 27) and Cohen and Cohen (1975, p. 229) have noted, classical analysis of variance techniques that 'block' on the aptitudes to produce groups that can be labeled 'low', 'medium', and 'high' on a particular aptitude result in the loss of both information and statistical power. The 'blocks' inevitably have unequal cell sizes producing independent variables that are not orthogonal.

The alternative to the use of ANOVA techniques is the use of multiple linear regression. 'Dummy' variables may be coded by the treatment effects and these used to produce interaction variables with the aptitudes. Several methods are available for this coding. Cohen and Cohen (1975, Chapter Five) present four methods: dummy, effects, contrasts, and nonsense coding. While the overall multiple R^2 and therefore the F value are always the same no matter what coding method is used, the three methods allow for different hypotheses to be tested within the types of treatment.

In effects coding, as Cohen and Cohen (1975, p. 194) pointed out, the method takes as its reference point all of the groups taken as an equally weighted aggregate. The null hypothesis under test is that the dependent variable mean for group i is equal to the mean of the means of the dependent variable of all the groups. This was the question under consideration for this research, therefore effects coding was used as the method for coding the treatment conditions. Figure 4 shows the coding diagram.

The four treatments can be fully represented by three dummy variables (X_1 , X_2 , X_3) representing the three degrees of freedom available. These dummy variables were used to represent the interactions of interest. If the

Treatment	Dummy Variables X_1	 X_2	 X_3
Factor-Label - T_F	-1	-1	-1
Diagram - T_D	0	1	0
Analogy - T_A	1	0	0
Proportions - T_P	0	0	1

Figure 4. Coding of dummy variables.

aptitude of Verbal Preference is represented by V, Visual Preference by I, and Mathematics Anxiety by M, the Proportional Reasoning Ability by P, the interactions produced were VI, VM, VP, IM, IP, MP, VIM, VIP, VMP, IMP, VIMP, VX_1, VX_2, VX_3, IX_1, IX_2, IX_3, MX_1, MX_2, MX_3, VIX_1, VIX_2, VIX_3, etc.

Variables for each dependent measure were entered into the regression equations in the following order:

Verbal and Visual Preference
Mathematics Anxiety
Proportional Reasoning Ability
Treatment
Verbal/Visual Preference by Treatment Interaction
Mathematics Anxiety by Treatments Interactions
Proportional Reasoning Ability by Treatments Interaction
Verbal with Visual by Treatments Interaction
Verbal or Visual with Mathematics Anxiety by Treatments Interaction
Verbal or Visual with Proportional Reasoning by Treatment Interaction
Proportional Reasoning with Mathematics Anxiety by Treatment Interactions
Verbal with Visual with Mathematics Anxiety by Treatment Interactions
Verbal with Visual with Proportional Reasoning by Treatment Interactions
Verbal or Visual with Mathematics Anxiety with Proportional Reasoning by Treatment Interactions
Verbal with Visual with Mathematics Anxiety with Proportional Reasoning by Treatment Interactions

The order of entering the variables into the regression equation was based on "weakness" of the aptitude. The verbal and visual aptitudes were entered first (on an equal basis) because from a review of the literature they appeared to have the least construct validity. Mathematics anxiety ratings and proportional reasoning ability had increasing degrees of construct validity in the order stated.

By placing verbal preference, visual preference, and mathematics anxiety into the regression equation before proportional reasoning ability, any shared variance would be considered in the weaker constructs. This would have the proportional reasoning ability aptitude uncontaminated by the shared variance (Cohen and Cohen, 1975, p. 327).

This study utilized univariate multiple regression as an analytical tool rather than multivariate linear regression for the following reasons:

1. Four different chemistry topics were studied. Although some of these have similarities (involve moles) each has distinct characteristics. In particular the unit on gas laws contains concepts quite different from the other three units. Because the units were on different topics, it was of interest to determine if a particular strategy was particularly suited to a given chemistry topic.

Within the units, the two dependent variables, immediate posttest and delayed posttest, were analyzed separately because of the different nature of the tests. The immediate posttests were given immediately after students' studied each lesson and contained the strategy used at the top of each test page. The delayed posttests had no aids and included at least two transfer items.

2. A multivariate analysis would have been most complex to analyze and to interpret because of the 15 dependent variables involved.

3. Correlation for most of the dependent variables were modest ranging from .20 to .76.

In the instance where the correlation was likely to be the greatest (moles and stoichiometry). Robert Sherwood, a doctoral graduate assistant working on this project, analyzed the data in this manner for a doctoral dissertation study. Sherwood's (1980) results are consistent with those found using the univariate method.

In the same dissertation, factor analyses of several measures utilized in this study were made. Persons interested in the factor analysis of the verbal-visual preference item, the proportional reasoning ability test, and several of the measures of problem solving ability might consult this dissertation.

Hypotheses 64 - 68 were analyzed as follows:

Hypothesis 64. A t-test was used to determine the differences between the two sets of scores.

Hypothesis 65. A one way analysis of variance was used to determine differences in achievement according to whether students used mneumonic notation in problem solving. Differences between means were examined using the Scheffé procedure.

Hypothesis 66. A chi-square analysis was used to determine whether students classified according to strategy taught used no, some, or extensive notation in problem solving.

Hypothesis 67. 2 x 2 analyses of variance were used to determine differences in time spent according to matched or mismatched strategies and verbal and visual aptitudes. Students were classified as having a visual method of instruction if they used the analogy or diagrammatic method. Students using the factor-label method or proportionality comprised the verbal methods group. Students with scores less than 14 were considered low verbal; those equal or greater than 14 were classified high verbal. The cut off point for the imagery scores was 18. These numbers were selected because their use divided the students into two groups of approximately the same size.

Hypothesis 68. This hypothesis was tested using 2 x 2 analyses of variance. Students were classified as high or low in proportional reasoning ability according to whether their score was less than 14 or equal to or greater than 14.

The proportional reasoning teaching strategy was singled out as the one that matched proportional reasoning ability. Students using the factor-label method, analogy method and diagrammatic method formed the non-proportional reasoning teaching strategy group.

Missing data for the aforementioned analyses was handled in the same way. If a single item on a test was left blank, a zero was used as the score. If one immediate posttest was missing, the grand mean was substituted. If more than two dependent measures were missing, the student was dropped from the study. In cases where the score on a dependent measure was replaced with the grand mean, the number of degrees of freedom was reduced by one.

Analysis of the questionnaire was made informally by tabulating comments where possible and presenting data in terms of percentages.

Results

Results of the aptitude by treatment interaction study are summarized in Table 4. Appendix H gives summary tables of the multiple regression analyses. Results are given in terms of individual hypotheses. For all dependent variables a general regression equation and a main effects regression equation were calculated. Because these equations pertain to several hypotheses, they are not included with the information on the main effects (hypotheses 1 - 4) but appear with discussion of the first significant interaction effect. If there were no significant interactions, the tables appear after the discussion of those that were significant.

Hypothesis 1

Regression coefficients and the change in R^2 for hypotheses one through three are given in Table 5. Examination of Table 4 shows that the verbal preference had no relationship to students performance on the dependent measures. In three instances visual preference was related. Students with high visual preference scored higher. However this accounted for only 1 or 2 percent of the variance.

Hypothesis 2

Students' mathematics anxiety was related to students' performance on all dependent measures. Table 4 shows that it was significant at the .01 level in almost every case. Table 5 shows that there was a negative relationship, that is, students who had a higher degree of mathematics anxiety had lower chemistry achievement. The percentage of variance for which mathematics anxiety accounted ranged from 1.0 to 4.7 percent, the latter referring to the Transfer Item Test. This seems reasonable as this dependent measure was the most difficult of those used in the study.

Hypothesis 3

Table 4 indicates that students' proportional reasoning ability was related to students' success on every department measure at the .01 level. From Table 5, one can see that as students' proportional reasoning ability increased, so did their chemistry achievement. Proportional reasoning ability was more strongly related to performance than any other aptitude or aptitude interaction measured in the study. The percentage of the variance accounted for ranged from 3.0% to 18.7%. The greatest amount of variance accounted for was in the ACS-NSTA Test which is particularly complex, and requires formal reasoning skills for many questions.

Hypotheses 4 - 8

The particular strategy (treatment) that students used to learn how to solve the chemistry problems in the four units of instruction had a significant effect on achievement in a limited way as can be seen from Table 4. In only three cases was there a significant difference. These were for the Moles and Gas Laws Immediate Posttests and for the Gas Laws Delayed Posttest. Table 24 shows that students who were taught by the factor-label method scored significantly higher on the Moles Immediate Posttest and students who used the proportionality method scored significantly lower. All comparisons were made with the grand mean.

Table 71 shows that this is not the case with achievement on the Gas Laws Immediate Posttest. For this unit the proportionality method was the most effective whereas both the diagram and analogy methods were the least effective. This is a reasonable finding because the gas laws are stated in terms of proportion and students were likely to memorize the formulas according to the proportionality method. In this particular unit, the diagram was more complex than in the other three units and the analogy may have been easily forgotten. Table 89 shows that on the Gas Law Delayed Posttest a similar result is found although the mean of the diagram method is not statistically different from the grand mean.

Hypotheses 9 - 13

Although no verbal preference by treatment interaction was found on any dependent measure a visual preference x treatment interaction was found for achievement as measured by the ACS-NSTA Examination in High School Chemistry. Results are found in Tables 6 - 11 and have been diagrammed in Figure 5. Students with low visual preference using the analogy treatment scored higher on this test.

These results were entirely unexpected. It was postulated that if a student had a high visual preference, then using a visual mode (analogies or diagrams) would produce superior results. The explanation may perhaps be that when students who did not have a visual preference were forced to use a visual presentation, this required them to pay a greater amount of attention to what they were doing and they therefore achieved more. Why this result is not consistent for all the other dependent measures is inexplicable.

Hypotheses 14 - 18

No significant differences were found for the mathematics anxiety by treatments interaction.

Hypotheses 19 - 23

The proportional reasoning ability by treatment interaction was shown to exist for the Nontransfer Items Test only. Results of this analysis are given in Tables 12 - 17 and are diagrammed in Figure 6. For the sake of comparing the Nontransfer Items Test results with the Trnasfer Items Test results, Tables 18 - 22, for the Transfer Items Test are included. A diagram of the Transfer Items Test results is given in Figure 7.

For the Nontransfer Items Test, students with low proportional reasoning ability who used the diagrammatic method were the least successful, whereas students with high proportional reasoning ability who used the diagram were the most successful. Figure 7 shows that this did not hold for the students who used the diagrammatic method for the Transfer Items Test. From the diagram given in Figure 7 it is rather surprising that no significant difference existed for the factor-label x treatment interaction. It may have been that there were in reality very few low proportional reasoning students who were assigned to the factor-label method where the crossing actually occurred. Why an interaction occurs for the Nontransfer Items Test is not known except that possibly the diagrams were complex and required proportional reasoning ability.

Hypotheses 24 - 28

A verbal x visual x treatment interaction was found to be significant on the Moles Immediate Posttest. Tables 23 - 28 show the analysis and the results are shown picturially in Figure 8. Students with low verbal preference and low visual preference scores and the analogy method did poorly on the test whereas those with low visual and verbal preferences using the proportionality method scored high. However, if students had a high verbal preference and low visual preference, the analogy treatment was best, and the proportionality treatment the worse.

Results of this same interaction are given for comparison sake for the other immediate posttests even though findings were not significant. Tables 29 - 30 and Figure 9 show that the trend is the same for the Gas Laws Immediate Posttest. For the Stoichiometry Immediate Posttest, the results given in Tables 31 and 32 and Figure 10, are not consistent with moles and the gas laws. For the low verbal, low visual students, the analogy treatment appears best. For the molarity unit, as shown in Tables 33 and 34 and Figure 11 the factor-label method appears superior, and the analogy method the poorest.

Because of such differing findings, generalization is difficult. At least for two units, however, for students of both low verbal preference and low visual preference, the proportionality approach appears superior. One wonders what actually characterizes students who have both a low verbal and low visual preference for learning. At the onset of the research, it was thought that these two approaches were mutually exclusive. By what approach would this type of student prefer to learn? Do they have no preference for learning or are they lethargic? Because it is impossible from the research reported here to characterize these students, generalization about their approach to learning chemistry problem solving is unwarranted.

Hypotheses 29 - 33

Significant interaction effects were found for two dependent measures, the Stoichiometry Immediate Posttest and the Decimal Subtest, for the visual preference by mathematics anxiety by treatment interaction. No significant differences were found for verbal preference.Tables 39 - 40 and Figure 12 present the data. As shown in Figure 12 for students with low visual preference and low mathematics anxiety, the factor-label method was superior and the diagrammatic method inferior. However, this is not the case for low visual preference students who had high mathematics anxiety. For these students, the diagrammatic method was best and the factor-label the worse. For these same students the analogy method was also better than the other two but as students' visual preference increased these differences diminished and the analogy method became preferred.

Tables 41 - 42 and Figure 13 give this same information for the moles unit. Although the findings are not significant, trends are the same for the low visual and low mathematics anxiety students. For the low visual, high mathematics anxiety students, diagrammatic and analogies methods remained superior.

For the gas law unit shown in Tables 43 - 44 and Figure 14, little differences are seen. However, analogies remain superior for the low visual - low mathematics anxiety group and diagrams best for the low visual - high mathematics anxiety group.

Tables 45 and 46 and Figure 15 give the results of the analysis for the molarity unit. Although it appears from Figure 15 that results are significant, they were not. Why they were not cannot be explained at this time. For the low visual, high mathematics anxiety students, the diagrammatic method was still superior. Other findings were not consistent with the trends for the other three units.

Results for the Decimal Subtest are given in Tables 47 - 52 and in Figure 16. Differences in achievement are most pronounced for the students who had low visual preference and high mathematics anxiety. For these students the preferred method of instruction was the use of diagrams. This was followed by the analogy method (not significant), the proportionality method was poorest although not significantly different from the mean. For students with low visual preference and low mathematics anxiety the reverse is true. The proportionality method was best (not significant) and the diagram method the poorest.

For the sake of comparison, data was analyzed for the Nondecimal Subtest. This consisted of the same problem except that no decimals were given in the original problem. Data analysis is given in Tables 53 - 57 and in Figure 17. Although results were not significant, a trend indicates that the diagram method might be superior for low visual, high mathematics anxiety students. For low visual, low mathematics anxiety students the factor-label method produced the highest scores followed by the proportionality method.

The results of this aptitude x treatment interaction is fairly consistent over the two dependent measures where significance was found. In both cases, the major differences appear where students had high mathematics anxiety and low visual preference versus those with low mathematics anxiety and low visual preference. Means for the cases of high visual preference - high mathematics anxiety and high visual preference - low mathematics anxiety for the various strategies did not differ to any great extent. Moreover, students with high mathematics anxiety and low visual preference did best with strategies that were intended to be visual. A possible explanation for the reason why these strategies might be best for this type of student combines the explanation given for the visual preference by treatment interaction (Hypotheses 9 - 13) and the students high mathematics anxiety. As mentioned previously, it may be that when students who did not prefer to learn by visual methods were required to do so, they paid more attention to what they were learning and consequently achieved more. This would be particularly true of the high mathematics anxiety student. The diagram method or the analogy method offered this student an additional mathematical terminology than would the more mathematical approaches (factor-label and proportionality). For the low mathematics anxiety student, the more mathematical and less visual approaches were more suitable. In fact, these students who did not have a high mathematics anxiety probably skimmed over the diagrams and analogies and therefore did poorly because they did not have factor-labels or proportions on which to depend.

Hypotheses 34 - 38

These hypotheses pertained to the visual or verbal preference by proportional reasoning by treatment interactions. No significant differences were found for the visual preference interactions on any dependent measures. However, there was a verbal preference by proportional reasoning ability by treatment interaction for the Molarity Delayed Posttest scores. Tables 58 - 63 and Figure 18 give the results. For students with low verbal preference and low proportional reasoning ability, or high verbal preference and high proportional reasoning ability, the analogy approach was best. When either of these aptitudes was low, the analogy method was the worst approach. Tables 64 - 69 and Figures 19 - 21 give the results for the Delayed Posttests of the other three chemistry units. Examination of the figures shows that these results are not consistent across the other units and in fact no consistent trends are apparent in the other three units. Because no significant differences were found on other dependent measures, the result is unique to this one unit and one dependent measure. Why this particular analogy for this subject matter wrought these results is not known.

Hypotheses 39 - 44

A mathematics anxiety by proportional reasoning ability by treatment interaction was found for achievement on the Gas Laws Immediate Posttest. As with significant findings of other interactions that involved mathematics anxiety, major differences occurred with students of high and low mathematics anxiety and low values on the other aptitudes. Resluts are given in Tables 70 - 75 and in Figure 22. Students with low proportional reasoning ability and low mathematics anxiety did best with the factor-label and proportional method (not significant) and worse with the diagram method. For students of low proportional reasoning ability and high mathematics anxiety the analogy method was superior (followed by the diagram method - not significant). The poorest method was factor-label. These same results for the factor-label method were found for students of low visual preference and low mathematics anxiety, and somewhat similar results were found for the analogy treatment. Apparently students who have low mathematics anxiety and were low on the other aptitude found the factor-label method attractive, whereas it is not a good method for high anxiety students. Results for the other three units although not significant are included in order to make comparisons. They are given in Tables 76 - 81 and in Figures 23 - 25. In every case, the factor-label method was best for students of low mathematics anxiety and low proportional reasoning ability. For students of high mathematics anxiety and low proportional reasoning ability, the diagrammatic method appears to have had the advantage (not significant), and in two of the three other units, the factor-label method was the poorest (trend only). When students had a high mathematics anxiety and no compensating aptitude (high proportional reasoning ability or high visual preference) the more mathematical approaches (factor-label and proportionality) were not desirable. This is in agreement with results found for hypotheses 29 - 33.

Hypotheses 45 - 63

No significant four way interactions were found. Tables 82 - 100 give the general regression equation, F tests for possible significant effects, and the main effects regression equation for analyses of dependent measures where no significant interaction effects were found.

Hypothesis 64

A significant difference between scores on the Decimal and Nondecimal Subtest was found as shown in Table 101. Students scored slightly better when the initial values given in the problems did not contain decimals. If teachers are interested in whether students understand how to solve a given problem, this might be achieved better if no decimals are included. This is not to say that at an intermediary point, a decimal will not be needed or that the answer will not be in decimal form. Although the means of the Decimal and Nondecimal Subtests are not drastically different, it must be recalled that most students used calculators in solving the problems and one might expect that this usage would obliterate any difference in scores.

Hypothesis 65

In order to test this hypothesis on the use of notation and achievement, students were asked to show their work in solving one of the stoichiometry problems on the ACS-NSTA Cooperative Examination administered at the end of the school year. Students' work was then classified into three categories: no notation, some notation, complete notation. Results of an analysis of variance and the Scheffé procedure are shown in Tables 102 and 103. The analyses indicate that a significant difference in achievement does exist according to the amount of notation used. Students using complete notation achieved higher scores on the test than students who used no and little notation.

Hypothesis 66

This hypothesis stipulated that there would be no differences in the amount of notation used according to the method students were taught to solve the chemistry problems. Data were analyzed using chi-square, and the results are given in Table 104. Although the results are not significant at the .05 level, means show that students who were assigned to the factor-label treatment more frequently used complete notation. This coupled with the results of hypothesis 65 indicates that if differences in aptitude are ignored, this method may be preferred over the other three.

Hypotheses 67 and 68

These two hypotheses pertain to the amount of time students spent studying a given unit according to whether the method used (treatment) matched or did not match their aptitudes. Hypothesis 67 dealt with verbal-visual preference and hypothesis 68 dealt with proportional reasoning ability.

To test the hypotheses a series of analyses of variance were run for individual lessons and for the total time for the gas laws and molarity units. Because there were no significant main or interaction effects for the total time and inconsistent ones for several of the individual lessons for the verbal-visual preference and verbal-visual treatments (hypothesis 67) no tables are presented. For the proportional reasoning ability and proportionality method, however, more consistent results were found. Time spent in learning four out of six of the individual lessons were significant at the .05 level. Total times had a probability level of .09 for the gas law unit and .07 for the molarity unit. Data are presented in Tables 105 - 108.

By comparing the Tables one can see that any significant findings are not uniform across the two units of instruction. For the molarity unit, there is a main effect in that students of high proportional reasoning ability completed the unit in a shorter period of time. This did not hold for the gas law unit where differences in time are not significant. For the gas law unit there is a significant interaction effect that does not exist for the molarity unit. The interaction was not anticipated. Students with high proportional reasoning ability spent more time when the proportionality method was used and low proportional reasoning students spent more time when they used nonproportionality methods (analogy, diagram, factor-label). In the molarity analysis, although the interaction is not significant, low proportionality students spent most time with the proportionality method. This appears to be more reasonable.

The results of the above analyses must be interpreted extremely cautiously. The number of subjects per cell was quite low, and the treatments in some units took longer to complete than others. This was generally true of the proportionality and analogy methods. It was for this reason that extra practice problems were included in the larger aptitude by treatment interaction study. For this analysis, times were recorded before students began the practice problems. Other complicating factors were that some students used calculators and others did not. There was little control over whether students marked their times properly or spent part of this time talking to one another rather than working. These two hypotheses were added as a result of the NSF director's meeting in March, 1980 and therefore little planning could take place to collect data and have the necessary controls. As a result of the above plus the additional factors of only being able to collect this data from a limited number of teachers over a short time span near the end of the school year with no provision for students to mark the time in their booklets, makes the findings tenuous. The question remains an interesting one, and probably should be pursued in a more controlled manner than was possible in this study.

Analysis of Questionnaires

The questionnaires that were administered at the end of the school year (Appendix E) were analyzed by tallying data according to treatment and teacher. It was felt that responses were candid because students were not allowed to identify themselves. Results are given in Tables 109 - 111 in terms of the four treatments.

Table 109 which summarizes the more objective questions shows that students more frequently skipped over parts (or all) of the diagram and analogy methods than the factor-label or proportionality method (question 1). This was supported from student's answers to question 9, a free response item where students listed what they liked least. Many students said that the analogies were stupid or insulting and the diagrams too complex, particularly for the gas law unit. In general skipping the reading was done more at the end of the year than at the beginning, except for the analogy unit where it seems quite uniform across units (question 2). In many cases, however, students commented that they skipped only when they understood the sample problems. If they didn't they went back and used the diagram and analogies to help them understand the material.

Students in general found the method to which they were assigned quite useful (question 3). This was true to a greater extent for students assigned to the factor-label and proportionality method. Students used the method all or most of the time (question 4).

Questions 4 - 7 were included to determine the degree of contamination within the study. Considering that the study lasted the entire school year, the 10% contamination rate (shown in question 5) is not surprising. This does not include students who listed responses classified as "other" on the summary. For the most part these students said that they learned to work the problem by studying the sample problems in the packet or by using their ingenuity. These answers cannot be considered to represent students not using their own booklets.

When students answered question 6 on how they modified the methods, the majority mentioned that they combined or eliminated steps. The high percentage of students that did this for the proportion unit is not unexpected. The proportions took more space to write out and were longer units because of this. They could easily have been shortened but the investigators felt that all steps should be shown in the packets.

From question 7, it can be seen that sometimes students did borrow another student's packet. Many mentioned that they were curious to see what the other packets contained, and really didn't use the packet to learn a different method.

Question 8 gave students an opportunity to state what they liked most about using the packets. Results are listed in Table 110 according to the frequency of response for 1% of the sample. Students most often mentioned that the packets were very explanatory, had answers (solutions) given, and were fast and easy.

The most common thing that students liked least was the length of the packets or the fact that there were too many. The next most common complaint was that they were monotonous and boring. This might be due to the fact that students frequently expressed a dislike for problems and felt that this was taking too much time from lab.

Although no data is summarized in this report according to classes or teachers, it was interesting to find variation in questions 8 and 9 according to teacher. Some students in particular classes said that this material was easy, students in other classes said it was too hard. In some classes, students complained that they didn't have enough time, whereas in another class this was never mentioned. In one particular set of classes where students complained that the material was boring, test scores were considerably below those reported by all other teachers. For this reason, even though more contamination of treatments was possible, by having all four treatments in each classroom the decision to design the study in this manner probably minimized these other effects over which no control was possible.

Summary and Conclusions

This aptitude by treatment interaction study has shown that the aptitudes of mathematics anxiety and proportional reasoning ability are related to students success in solving problems in high school chemistry. Students of high mathematics anxiety score significantly lower than students of low mathematics anxiety. Students of high proportional reasoning ability score higher than students of low proportional reasoning ability. Both of these findings are not surprising. Teachers are probably more aware of the relationship of proportional reasoning ability and success than the mathematics anxiety relationship. As teachers become more aware of the latter they will probably incorporate into their lessons teaching strategies that will reduce this anxiety.

Certain methods used in this study were less mathematical and more visual than others. These were the use of analogies and the use of diagrams. The more mathematical were the factor-label method and proportionality. The best method in general (main effect) for the moles unit where less contamination could be expected (used first in all classrooms) was the factor-label method and the worse method was proportionality. For the gas laws, however, in which the laws themselves are stated as proportions, the proportionality method was most effective and diagrams and analogies least effective. These results show that either the teaching strategies are subject matter specific or that the proportionality method becomes more effective over time (the gas laws were studied later in the school year in most instances).

Of more importance than the main effects in this study was the aptitude by treatment interaction findings. Of greatest interest are the results found for students of high mathematics anxiety and low scores on another aptitude. For students of this type, the less mathematical approaches frequently appear to be superior. It was found to be rather consistently true that the diagram method was superior for students of high mathematics anxiety and low visual preference for the immediate posttests for the four chemistry units (significant on trend in that direction). The same was true for the Decimal Subtest (significant) and Nondecimal Subtest (trend). For students having high mathematics anxiety and low proportional reasoning ability, the analogy method, the other less mathematical strategy, was best (significant) followed by the diagram method for the Gas Laws Immediate Posttest. Although not significant, the diagram method appeared to be somewhat better in two of the other three units on this same dependent measure.

These results seem to indicate that students with high mathematics anxiety and the absence of another aptitude (visual preference or proportional reasoning ability) profit by methods that contain supportive material that is not mathematical in nature. Analysis of the questionnaire substantiates this. Many students did not use the analogies or diagrams but skipped to the sample problems. These students were likely to be the low mathematics anxious students. (There was no way to check on this because students answered questionnaires anonymously.) Many students commented that they found the diagram and analogies beneficial and particularly so when they didn't understand the sample problems. Several commented that that is when they used the analogies or diagrams. These were probably the more mathematics anxious students.

These findings indicate that it might be profitable for teachers to use supplemental, less mathematical approaches with high mathematics anxious students who also are deficient in proportional reasoning ability or have low visual preference. These methods might also be profitable for either students if they are used more directly, that is, taught to the student by the teacher rather than from a packet. Students would probably be less likely to tune out the teacher explaining the diagram and analogy and could obtain immediate clarification.

Two less important findings from the first phase of this study were the positive relationship between success and the use of notation in problem solving, and the significant difference between the Decimal and Nondecimal Subtests. Students should be encouraged to label their numbers if they expect to be successful. Teachers, if they are testing for the understanding of concepts, should avoid using decimals in test problems.

Table 4

Summary of Results of Aptitude x Treatment Interaction Study

Hypothesis	Effect	MO QT	GL QT	S QT	ML QT	MO T	GL T	S T	ML T	ACS TOT	ACS PROB	ACS NPROB	TR	NTR	DE	NDE
1	V or I				.01[b]										.05[b]	.05[b]
2	M	.01[a]	.01	.01	.01	.05	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
3	P	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
4	Treatments	.01	.01				.05									
5	P	.01	.01													
6	A		.01				.01									
7	D		.05													
8	F	.05														
9	V or I x Treatments									.05[b]						
10	V or I x D															
11	V or I x A									.01[b]						
12	V or I x D															
13	V or T x F															
14	M x Treatments															
15	M x P															
16	M x A															
17	M x D															
18	M x F															

Table 4 (continued)

Summary of Results of Aptitude x Treatment Interaction Study

Hypothesis	Effect	MO QT	GL QT	S QT	ML QT	MO T	GL T	S T	ML T	ACS TOT	ACS PROB	ACS NPROB	TR	NTR	DE	NDE
19	P x Treatments													.05		
20	P x F															
21	P x A															
22	P x D													.05		
23	P x P															
24	V x I x Treatments	.01														
25	V x I x F															
26	V x I x A	.05														
27	V x I x D	.05														
28	V x I x P															
29	V or I x M x Treatments			$.05^b$											$.05^b$	
30	V or I x M x F			$.01^b$												
31	V or I x M x A			$.05^b$												
32	V or I x M x D			$.01^b$											$.01^b$	
33	V or I x M x P															
34	V or I x P x Treatments								$.05^c$							
35	V or I x P x F															
36	V or I x P x A								$.05^c$							

Table 4 (continued)

Summary of Results of Aptitude x Treatment Interaction Study

Hypothesis	Effect	MO QT	GL QT	S QT	ML QT	MO T	GL T	S T	ML T	ACS TOT	ACS PROB	ACS NPROB	TR	NTR	DE	NDE
37	V or I x P x D															
38	V or I x P x P															
39	M x P x Treatments		.05													
40	M x P x F		.05													
41	M x P x A		.05													
42	M x P x D															
43	M x P x P															
44	V x I x M x Treatments															
45	V x I x M X F															
46	V x I x M x A															
47	V x I x M x D															
48	V x I x M x P															
49	V x I x P x Treatments															
50	V x I x P x F															
51	V x I x P x A															
52	V x I x P x D															
53	V x I x P x P															

Table 4 (continued)

Summary of Results of Aptitude x Treatment Interaction Study

Hypothesis	Effect	MO QT	GL QT	S QT	ML QT	MO T	GL T	S T	ML T	ACS TOT	ACS PROB	ACS NPROB	TR	NTR	DE	NDE
54	V or I x M x P x Treatments															
55	V or I x M x P x F															
56	V or I x M x P x A															
57	V or I x M x P x D															
58	V or I x M x P x P															
59	V x I x M x P x Treatments															
60	V x I x M x P x F															
61	V x I x M x P x A															
62	V x I x M x P x D															
63	V x I x M x P x P															

[a] Level of significance
[b] I - Visual
[c] V - Verbal

Treatments	
Factor-Label	(F)
Analogy	(A)
Diagrams	(D)
Proportionality	(P)

Units	
Moles	(MO)
Gas Laws	(GL)
Stoichiometry	(S)
Molarity	(ML)

Aptitudes	
Verbal	(V)
Visual	(I)
Proportional Reasoning	(P)
Mathematics Anxiety	(M)

Dependent Measures	
Immediate Posttest (Quiz Total)	(QT)
Delayed Posttest	(T)
ACS-NSTA Examination in H.S. Chem.	(ACSTOT)
ACS-NSTA Problems Subtest	(ACSPROB)
ACS-NSTA Nonproblems Subtest	(ACSNPROB)
Transfer Items Test	(TR)
Nontransfer Items Test	(NTR)
Decimal Subtest	(DE)
Nondecimal Subtest	(NDE)

Table 5

Main Effects Summary, Hypotheses 1 - 3

Dependent Measures	Aptitudes							
	VVQV		VVQI		MARSTOT		PPRT	
	B	ΔR^2	B	ΔR^2	B	ΔR^2	B	ΔR^2
MOQT	-.0240	.0001	+.0392	.0022	-.0077	.0241	+.2006	.0744
GLQT	-.0249	.0006	+.0298	.0034	-.0051	.0202	+.0700	.0302
SQT	-.0140	.0004	+.0375	.0015	-.0076	.0244	+.1281	.0725
MLQT	-.0154	.0013	+.1122	.0223	-.0055	.0150	+.1583	.0623
MOT	+.0052	.0017	+.0269	.0036	-.0016	.0103	+.1735	.1125
GLT	-.0316	.0020	+.0220	.0019	-.0048	.0131	+.1305	.0664
ST	-.0317	.0005	-.0193	.0005	-.0090	.0356	+.1737	.0818
MLT	-.0068	.0000	+.0109	.0002	-.0061	.0231	+.1460	.0595
ACSTOT	-.0197	.0002	-.0356	.0018	-.1026	.0302	+.5486	.1867
ACSPROB	+.0092	.0002	+.0293	.0021	-.0044	.0215	+.1966	.1367
ACSNPROB	+.0069	.0009	+.0524	.0006	-.0073	.0236	+.3937	.1609
TR	-.0170	.0018	+.0039	.0017	-.0066	.0468	+.1745	.1378
NTR	-.0519	.0001	+.0318	.0014	-.0157	.0440	+.4770	.1455
DE	-.0130	.0003	+.0575	.0104	-.0051	.0223	+.1197	.0742
NDE	-.0271	.0023	+.0427	.0133	-.0048	.0364	+.0812	.0584

Units	
Moles	(MO)
Gas Laws	(GL)
Stoichiometry	(S)
Molarity	(ML)

Aptitudes	
Verbal	(VVQV)
Visual	(VVQI)
Proportional Reasoning	(MARSTOT)
Mathematics Anxiety	(PPRT)

Dependent Measures	
Immediate Posttest (Quiz Total)	(QT)
Delayed Posttest	(T)
ACS-NSTA Examination in H.S.Chem.	(ACSTOT)
ACS-NSTA Problems Subtest	(ACSPROB)
ACS-NSTA Nonproblems Subtest	(ACSNPROB)
Transfer Items Test	(TR)
Nontransfer Items Test	(NTR)
Decimal Subtest	(DE)
Nondecimal Subtest	(NDE)

Table 6

ACS-NSTA Chemistry Achievement Test (ACSTOT):

General Regression Equation

$$
\begin{aligned}
\text{ACSTOT} = {} & -.0197(\text{V}) - .0356(\text{I}) - .10258(\text{MARSTOT} + .5486(\text{PPRT}) \\
& 132.943(\text{X3}) - 45.975(\text{X2}) - 91.447(\text{X1}) + 5.200(\text{VX2}) \\
& + 2.645(\text{VX1}) - 8.140(\text{VX3}) - 5.328(\text{IX3}) + 1.085(\text{IX2}) \\
& + 5.292(\text{IX1}) + .5236(\text{MX1}) - .7576(\text{MX3}) + .2479(\text{MX2}) \\
& + 6.907(\text{PX2}) + 3.655(\text{PX1}) - 8.789(\text{PX3}) - .1930(\text{VIX1}) \\
& + .3486(\text{VIX3}) - .1975(\text{VIX2}) - .0165(\text{VMX1}) - .0261 \\
& (\text{VMX2}) + .0466(\text{VMX3}) - .0327(\text{IMX1}) + .0328(\text{IMX3}) \\
& - .00736(\text{IMX2}) - .5980(\text{VPX2}) - .0193(\text{VPX1}) + .4938 \\
& (\text{VPX3}) - .2216(\text{IPX1}) + .3426(\text{IPX3}) - .2694(\text{IPX2}) - \\
& .0238(\text{PMX1}) - .0346(\text{PMX2}) + .04780(\text{PMX3}) + .00132 \\
& (\text{VIMX1}) - .00216(\text{VIMX3}) + .00103(\text{VIMX2}) + .00513 \\
& (\text{VIPX1}) + .0258(\text{VIPX2}) - .0206(\text{VIPX3}) + .000372 \\
& (\text{VPMX1}) + .00306(\text{VPMX2}) - .00279(\text{VPMX3}) + .00161 \\
& (\text{IPMX1}) + .00139(\text{IPMX2}) - .00199(\text{IPMX3}) - .0000548 \\
& (\text{VIPMX1}) - .000133(\text{VIPMX2}) + .000127(\text{VIPMX3}) \\
& + 14.225
\end{aligned}
$$

Where $\overline{\text{VVQV}}\ (\bar{\text{V}}) = 15.807$ $\quad \overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}\ (\bar{\text{I}}) = 18.020$ $\quad \overline{\text{PPRT}} = 12.614$

Table 7

ACS-NSTA Chemistry Achievement Test (ACSTOT):

Main Effects Regression Equation

Equation: ACSTOT = -.0114 (MARSTOT) + .552 (PPRT) + 13.819

Table 8

ACS-NSTA Chemistry Achievement Test (ACSTOT):

F Tests for Possible Significant Effects

Mean = 17.969 S.D. = 5.368 Cases = 528 Max. = 40

Predictor	ΔR^2	F	Sig.Level
MARSTUT	.03019	.03019/.001526[a] = 19.78	.01
PPRT	.18671	.18671/.001526 = 122.35	.01
IX3	.00026	$\frac{.01249/3}{.001526} = 2.73$	.05
IX2	.01199		
IX1	.00024		
	.01249		
IX3	.00026	.00026/.001526 = .17	NS[b]
IX2	.01199	.01199/.001526 = 7.86	.01
IX1	.00024	.00024/.001526 = .16	NS
IMX1	.00750	$\frac{.00778/3}{.001526} = 1.70$	NS
IMX3	.00008		
IMX2	.00020		
	.00778		
PMX1	.00144	$\frac{.00883/3}{.001526} = 1.93$	NS
PMX2	.00022		
PMX3	.00717		
	.00883		

---

[a] Error Term = (1-.29786)/475-15 = .001526

[b] NS = Nonsignificant

Table 9

ACS-NSTA Chemistry Achievement Test (ACSTOT):

Calculations for "Fourth" Effect

Visual X Treatment Interaction

Effect	B	S.E.B.
IX3	+.158	.103
IX2	-.287	.102
IX1	+.0417	.104

$$B_4 = -\Sigma B_i = -(.158 - .287 + .0417) = .0873$$

$$S.E.B._4 = \Sigma \frac{S.E.B._i}{3} = \frac{.103 + .102 + .104}{3} = .103$$

$$t_4 = \frac{B_4}{S.E.B._4} = \frac{.0873}{.103} = .85 \qquad \text{NS}$$

Table 10

ACS-NSTA Chemistry Achievement Test (ACSTOT):

Visual Preference (VVQI) X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$ACSTOT = .1538I + 15.115$
Analogy	$X2 = 1$	$ACSTOT = -.3384I + 24.289$
Diagram	$X1 = 1$	$ACSTOT = -.0194I + 17.912$
Factor-Label	$X3 = X2 = X1 = -1$	$ACSTOT = .0615I + 16.732$

Table 11

ACS-NSTA Chemistry Achievement Test (ACSTOT): Substitution of Extreme Values for VVQI (2 → 23)

VVQI		TREATMENT		PREDICTED ACSTOT
2	.31	P	15.115	15.42
23	3.54	P	15.115	18.65
2	-.68	A	24.289	23.61
23	-7.78	A	24.289	16.51
2	-.04	D	17.912	17.87
23	-.45	D	17.912	17.47
2	.12	F	16.732	16.85
23	1.41	F	16.732	18.15

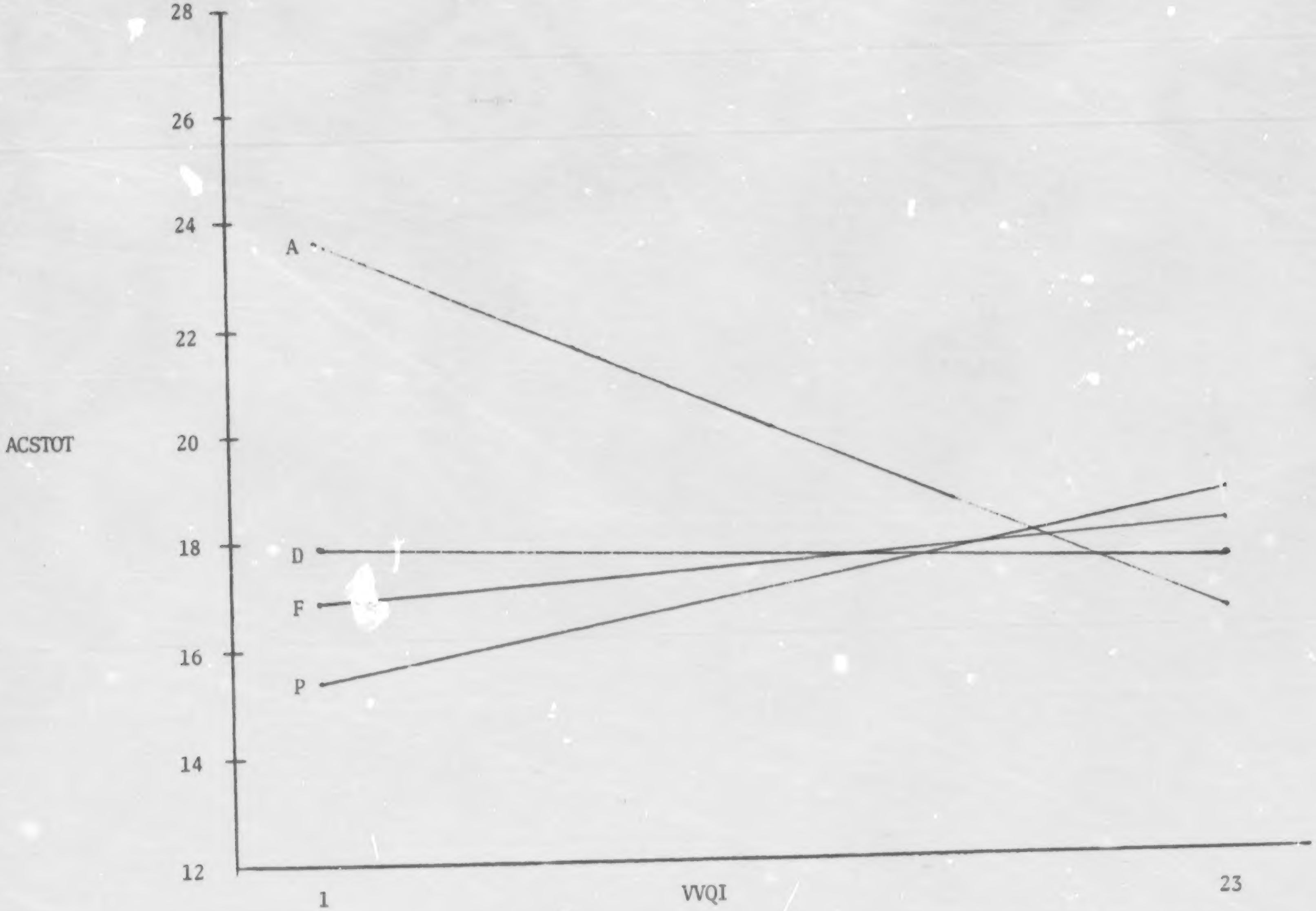

Figure 5. ACS-NSTA Chemistry Achievement Test (ACSTOT): Visual Preference (VVQI) X Treatment (X1-X3) Interaction

Table 12

Nontransfer Items Test (NTR): General Regression Equation

$$
\begin{aligned}
\text{NTR} = {} & -.0519(\text{V}) + .0318(\text{I}) - .0157(\text{MARSTOT}) + .4770(\text{PPRT}) \\
& - 4.409(\text{X2}) + 2.844(\text{X1}) - .5345(\text{X3}) - 2.000(\text{VX2}) \\
& + .4392(\text{VX3}) + 1.569(\text{VX1}) + .8081(\text{IX3}) - .2881(\text{IX1}) \\
& + .4030(\text{IX2}) - .0802(\text{MX1}) - .1650(\text{MX3}) + .1201(\text{MX2}) \\
& + 1.233(\text{PX2}) - 2.973(\text{PX1}) + 2.797(\text{PX3}) - .0899(\text{VIX1}) \\
& - .0677(\text{VIX3}) + .0835(\text{VIX2}) - .00836(\text{VMX1}) + .00685 \\
& (\text{VMX2}) + .0111(\text{VMX3}) + .00470(\text{IMX3}) + .00402(\text{IMX1}) \\
& - .00747(\text{IMX2}) + .1099(\text{VPX2}) - .0461(\text{VPX1}) - .1811 \\
& (\text{VPX3}) + .1756(\text{IPX1}) - .2107(\text{IPX3}) - .0812(\text{IPX2}) \\
& + .0195(\text{PMX1}) - .0146(\text{PMX2}) + .00158(\text{PMX3}) - .000322 \\
& (\text{VIMX3}) + .000491(\text{VIMX1}) - .000245(\text{VIMX2}) + .00204 \\
& (\text{VIPX1}) - .00328(\text{VIPX2}) + .0133(\text{VIPX3}) - .000249(\text{VPMX2}) \\
& + .000375(\text{VPMX1}) - .000293(\text{VPMX3}) + .000846(\text{IPMX2}) - \\
& .00101(\text{IPMX1}) + .000242(\text{IPMX3}) + .000000575(\text{VIPMX2}) \\
& - .0000216(\text{VIPMX1}) - .00000702(\text{VIPMX3}) + 18.265
\end{aligned}
$$

Where $\overline{\text{VVQV}}\ (\overline{\text{V}}) = 15.807$ $\qquad$ $\overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}\ (\overline{\text{I}}) = 18.020$ $\qquad$ $\overline{\text{PPRT}} = 12.614$

Table 13

Nontransfer Itesm Test (NTR): Main Effects Regression Equation

Equation: $NTR = -.0158\ (MARSTOT) + .482\ (PPRT) + 18.935$

Table 14

Nontransfer Items Test (NTR): F Tests for Possible Significant Effects

Mean = 21.234 S.D. = 5.296 Cases = 436 Max. = 30

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.04400	.04400/.001891[a] = 23.27	.01
PPRT	.14551	.14551/.001891 = 76.95	.01
VX2 VX3 VX1	.00008 .00094 .00458 .00560	$\frac{.00560/_3}{.001891} =$ .987	NS[b]
PX2 PX1 PX3	.00209 .01138 .00222 .01569	$\frac{.01569/_3}{.001891} =$ 2.77	.05
PX2	.00209	.00209/.001891 = 1.11	NS
PX1	.01138	.01138/.001891 = 6.02	.05
PX3	.00222	.00222/.001891 = 1.18	NS
VIPX1 VIPX2 VIPX3	.00020 .00004 .00896 .00920	$\frac{.00920/_3}{.001891} =$ 1.62	NS

[a] Error Term = (1-.27583)/383 = .001891

[b] NS = Nonsignificant

Table 15

Nontransfer Items Test (NTR): Calculations for "Fourth" Effect

Proportional Reasoning X Treatment Interaction

Effect	B	S.E.B.
PX2	+.0107	.0897
PX1	+.261	.0957
PX3	-.114	.103

$B_4 = -\Sigma\ B_i = (.0107+.261-.114) = -.158$

$\text{S.E.B.}_{\cdot 4} = \Sigma\ \frac{\text{S.E.B.}_{\cdot i}}{3} = \frac{.0897 + .0957 + .103}{3} = .0961$

$t_4 = \frac{B_4}{\text{S.E.B.}_{\cdot 4}} = \frac{-.158}{.0961} = -1.64$ NS

Table 16

Nontransfer Items Test (NTR):

Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$NTR = .2757P + 17.440$
Analogy	$X2 = 1$	$NTR = .4725P + 14.570$
Diagram	$X1 = 1$	$NTR = .7190P + 11.958$
Factor-Label	$X3 = X2 = X1 = -1$	$NTR = .4382P + 16.514$

Table 17

Nontransfer Items Test (NTR): Substitution of Extreme Values for PPRT (1 → 21)

PPRT		TREATMENT		PREDICTED NTR
1	.28	P	17.440	17.72
21	5.79	P	17.440	23.23
1	.47	A	14.570	15.04
21	9.92	A	14.570	24.49
1	.72	D	11.958	12.68
21	15.10	D	11.958	27.06
1	.44	F	16.514	16.95
21	9.20	F	16.514	25.72

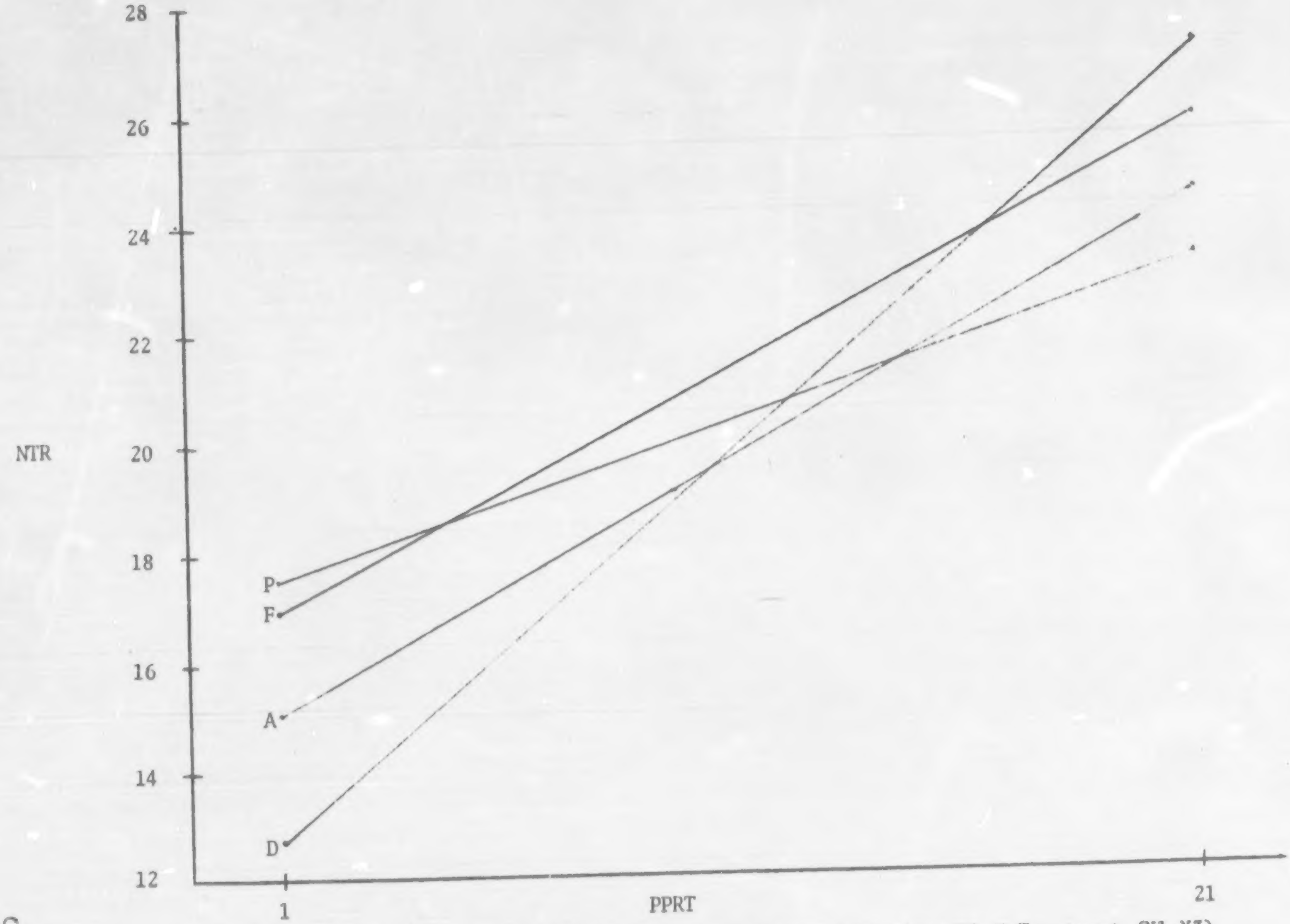

Figure 6. Nontransfer Items Test (NTR): Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Table 18

Transfer Items Test (TR): General Regression Equation

$$\begin{aligned}
\mathrm{TR} = {} & -.0170(\mathrm{V}) + .00392(\mathrm{I}) - .00656(\mathrm{MARSTOT}) + .1745(\mathrm{PPRT}) \\
& + 34.333(\mathrm{X3}) - 19.197(\mathrm{X2}) - 31.051(\mathrm{X1}) + .3743(\mathrm{VX2}) \\
& - 2.165(\mathrm{VX3}) + 2.634(\mathrm{VX1}) - 1.458(\mathrm{IX3}) + 1.870(\mathrm{IX1}) \\
& + 1.396(\mathrm{IX2}) + .1540(\mathrm{MX1}) - .2790(\mathrm{MX3}) + .1804(\mathrm{MX2}) \\
& + .8381(\mathrm{PX2}) + 1.039(\mathrm{PX1}) - 1.839(\mathrm{PX3}) - .1474(\mathrm{VIX1}) \\
& + .0879(\mathrm{VIX3}) - .0433(\mathrm{VIX2}) - .0125(\mathrm{VMX1}) - .00761 \\
& (\mathrm{VMX2}) + .0177(\mathrm{VMX3}) + .0128(\mathrm{IMX3}) - .00983(\mathrm{IMX1}) - \\
& .0110(\mathrm{IMX2}) + .0514(\mathrm{VPX2}) - .1344(\mathrm{VPX1}) + .1106(\mathrm{VPX3}) \\
& - .0691(\mathrm{IPX1}) + .0711(\mathrm{IPX3}) - .0774(\mathrm{IPX2}) - .00442(\mathrm{PMX1}) \\
& - .0117(\mathrm{PMX2}) + .0167(\mathrm{PMX3}) - .000777(\mathrm{VIMX3}) + .000727 \\
& (\mathrm{VIMX1}) + .000498(\mathrm{VIMX2}) + .00760(\mathrm{VIPX1}) - .000572(\mathrm{VIPX2}) \\
& - .00396(\mathrm{VIPX3}) + .000196(\mathrm{VPMX2}) + .000584(\mathrm{VPMX1}) - \\
& .0000997(\mathrm{VPMX3}) + .000742(\mathrm{IPMX2}) + .000364(\mathrm{IPMX1}) - \\
& .000749(\mathrm{IPMX3}) - .0000191(\mathrm{VIPMX2}) - .0000364(\mathrm{VIPMX1}) \\
& + .0000416(\mathrm{VIPMX3}) + 4.984
\end{aligned}$$

Where $\overline{\mathrm{VVQV}}\ (\overline{\mathrm{V}}) = 15.807$ $\qquad$ $\overline{\mathrm{MARSTOT}} = 184.546$

$\overline{\mathrm{VVQI}}\ (\overline{\mathrm{I}}) = 18.020$ $\qquad$ $\overline{\mathrm{PPRT}} = 12.614$

Table 19

Transfer Items Test (TR): Main Effects Regression Equation

Equation: $TR = -.00616\ (MARSTOT) + .175\ (PPRT) + 5.208$

Table 20

Transfer Items Test (TR): F Tests for Possible Significant Effects

Mean = 5.818 S.D. = 1.971 Cases = 435 Max. = 10

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.04684	.04684/.001901[a] = 24.64	.01
PPRT	.13779	.13779/.001901 = 72.48	.01
VIPX1	.00046	$\frac{.00926/_3}{.001901} = 1.62$	NS[b]
VIPX2	.00562		
VIPX3	.00318		
	.00926		
IPMX2	.00545	$\frac{.00772/_3}{.001901} = 1.35$	NS
IPMX1	.00181		
IMPX3	.00046		
	.00772		

---

[a] Error Term = (1-.27372)/382 = .001901

[b] NS = Nonsignificant

Table 21

Transfer Items Test (TR):

Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$TR = .1064P + 4.318$
Analogy	$X2 = 1$	$TR = .1436P + 3.807$
Diagram	$X1 = 1$	$TR = .1936P + 3.354$
Factor-Label	$X3 = X2 = X1 = -1$	$TR = .4684P + 2.823$

Table 22

Transfer Items Test (TR):

Substitution of Extreme Values for

PPRT (1 →21)

PPRT		TREATMENT		PREDICTED TR
1	.11	P	4.318	4.42
21	2.23	P	4.318	6.55
1	.14	A	3.807	3.95
21	3.02	A	3.807	6.82
1	.19	D	3.354	3.55
21	4.07	D	3.354	7.42
1	.47	F	2.823	3.29
21	9.84	F	2.823	12.66

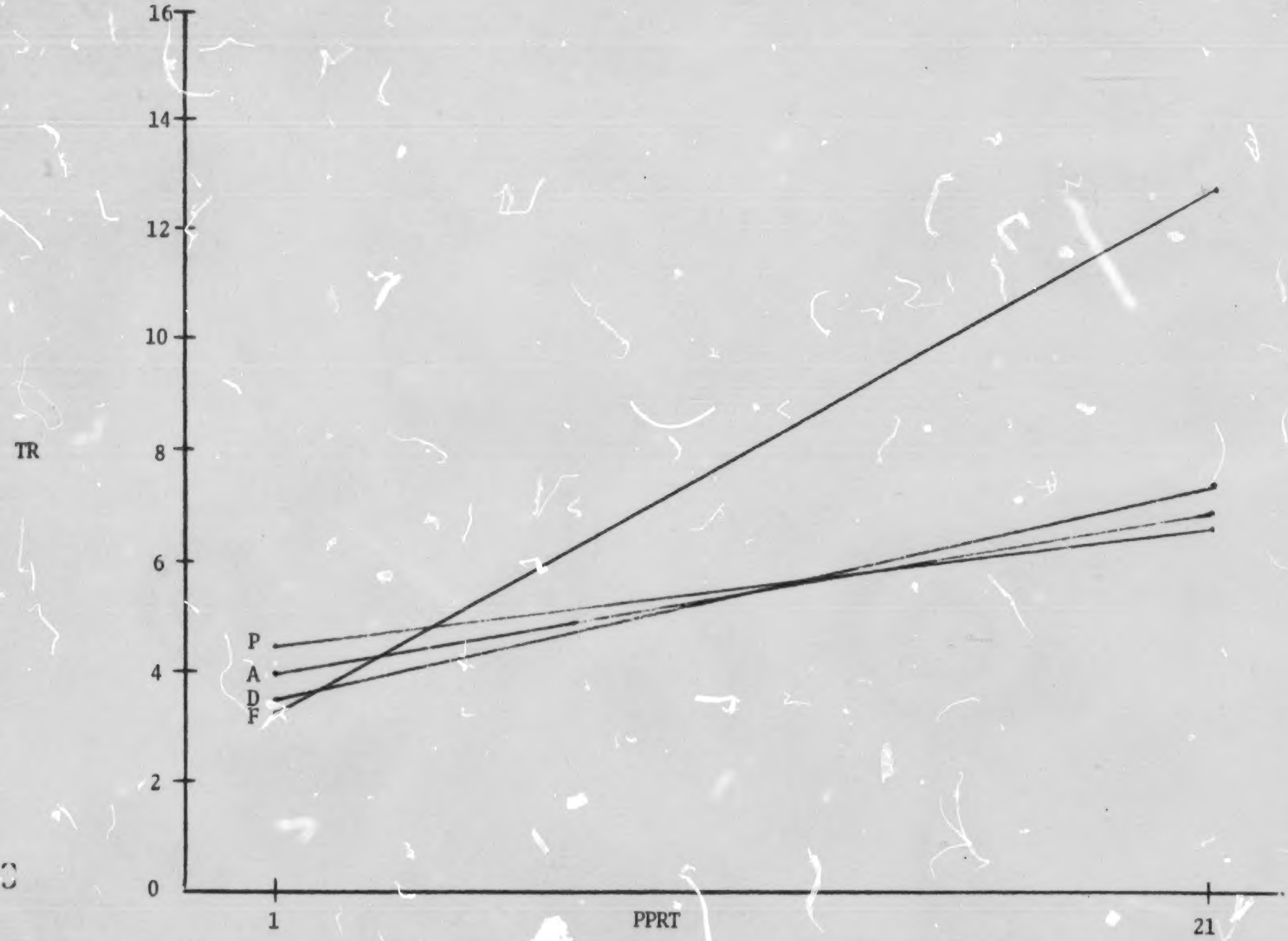

Figure 7. Transfer Items Test (TR): Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Table 23

Moles Immediate Posttest (MOQT): General Regression Equation

$$
\begin{aligned}
\text{MOQT} = {} & -.0240(\text{V}) + .0392(\text{I}) - .00765(\text{MARSTOT}) + .2006(\text{PPRT}) + \\
& 94.073(\text{X3}) + 7.437(\text{X2}) - 77.426(\text{X1}) - .9334(\text{VX2}) + \\
& 2.862(\text{VX1}) - 5.322(\text{VX3}) - 5.195(\text{IX3}) - .5553(\text{IX2}) + \\
& 4.721(\text{IX1}) + .3781(\text{MX1}) - .5833(\text{MX3}) - .0219(\text{MX2}) + \\
& .7620(\text{PX2}) + 4.069(\text{PX1}) - 6.328(\text{PX3}) - .1993(\text{VIX1}) + \\
& .2767(\text{VIX3}) + .0623(\text{VIX2}) - .0141(\text{VMX1}) + .00625(\text{VMX2}) + \\
& .0322(\text{VMX3}) - .0244(\text{IMX1}) + .0327(\text{IMX3}) + .00139(\text{IMX2}) - \\
& .0207(\text{VPX2}) - .1286(\text{VPX1}) + .3733(\text{VPX3}) - .2484(\text{IPX1}) + \\
& 3456(\text{IPX3}) - .0241(\text{IPX2}) - .0198(\text{PMX1}) - .00895(\text{PMX2}) + \\
& .0434(\text{PMX3}) + .00108(\text{VIMX1}) - .00174(\text{VIMX3}) - .000355 \\
& (\text{VIMX2}) + .00987(\text{VIPX1}) - .000272(\text{VIPX2}) - .0195(\text{VIPX3}) + \\
& .000699(\text{VPMX1}) + .000294(\text{VPMX2}) - .00256(\text{VPMX3}) + .00134 \\
& (\text{IMPX1}) + .000411(\text{IMPX2}) - .00242(\text{IPMX3}) - .0000612(\text{VIPMX1}) \\
& - .00000984(\text{VIPMX2}) + .000139\ (\text{VIPMX3}) + 15.653
\end{aligned}
$$

Where $\overline{\text{VVQV}}\ (\bar{V}) = 15.807$ $\qquad$ $\overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}\ (\bar{I}) = 18.020$ $\qquad$ $\overline{\text{PPRT}} = 12.614$

Table 24

Moles Immediate Posttest (MOQT): Main Effects Regression Equation

Equation: $\text{MOQT} = -.00675\ (\text{MARSTOT}) + .197\ (\text{PPRT}) - .887\ (X3) + .0471\ (X2) + .404\ (X1) + 16.018$

Where $\overline{\text{MARSTOT}} = 184.56$ $\overline{\text{PPRT}} = 12.614$

Strategy	Dummy Variables	MOQT
Proportion	X3 = 1	16.370[a]
Analogy	X2 = 1	17.304
Diagram	X1 = 1	17.661
Factor-Label	X3 = X2 = X1 = -1	17.693[b]

[a] Significantly lower than mean

[b] Significantly higher than mean

Table 25

Moles Immediate Posttest (MOQT): F Tests for Possible Significant Effects

Mean = 17.191 S.D. = 3.041 Cases = 528 Max. = 21

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.02408	.02408/.0017107[a] = 14.08	.01
PPRT	.07441	.07441/.0017107 = 43.50	.01
X3	.02213	$\frac{.02936/3}{.0017107} = 5.72$	.01
X2	.00126		
X1	.00597		
	.02936		
X3	.02213	.02213/.0017107 = 12.93	.01
X2	.00126	.00126/.0017107 = 0.74	NS[b]
X1	.00597	.00597/.0017107 = 3.49	NS
VIX1	.01028	$\frac{.02082/3}{.0017107} = 4.06$	.01
VIX3	.00316		
VIX2	.00738		
	.02082		
VIX1	.01028	.01028/.0017107 = 6.01	.05
VIX3	.00316	.00316/.0017107 = 1.85	NS
VIX2	.00738	.00738/.0017107 = 4.31	.05
IMX1	.00849	$\frac{.01214/3}{.0017107} = 2.37$	NS
IMX3	.00364		
IMX2	.00001		
	.01214		
VPMX1	.00599	$\frac{.00652/3}{.0017107} = 1.27$	NS
VPMX2	.00053		
VMPX3	.00000		
	.00652		

[a] Error Term = (1-R full)/df full = $\frac{1-.23699}{475-29}$ = .0017107

[b] NS = Nonsignificant

Table 26

Moles Immediate Posttest (MOQT): Calculations for "Fourth" Effect

Factor-Label Treatment Effect (Cohen and Cohen, 1975 p.193)

$$t_g = \frac{-g \, \Sigma \, B_i}{\sqrt{\tilde{s}d^2{}_{Y-\hat{Y}} \left[\frac{(g-1)^2}{ng} + \Sigma \frac{1}{n_i} \right]}} \qquad df = n-k-1$$

$$\tilde{s}d^2{}_{Y-\hat{Y}} = \tilde{s}d^2{}_{Y} \, (1-R^2) \, \frac{n}{n-k-1} = 3.041^2 \, (1-.13011) \, \frac{528-29}{528-7-1-29} = 8.176$$

$$t_4 = \frac{-4(-.887 + .0471 + .404)}{\sqrt{8.176 \left[\frac{(3)^2}{135} + \frac{1}{121} + \frac{1}{136} + \frac{1}{136} \right]}}$$

$$t_4 = \frac{1.744}{\sqrt{8.176(.08964)}} = 2.04 \qquad \text{Sig. at } p < .05$$

Verbal X Visual X Treatment Interaction

Effect	B	S.E.B.
VIX1	-.0194	.00959
VIX3	+.0235	.0109
VIX2	-.0227	.0107

$$B_4 = - \, \Sigma \, B_i = -(-.0194 + .0235 - .0227) = .0186$$

$$S.E.B._4 = \Sigma \, \frac{S.E.B._i}{3} = \frac{.00959 + .0109 + .0107}{3} = .0104$$

$$t_4 = \frac{B_4}{S.E.B._4} = \frac{.0186}{.0104} = 1.79 \qquad \text{NS}$$

Table 27

Moles Immediate Posttest (MOQT):
Verbal Preference (VVQV) X Visual Preference (VVQI) X
Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$MOQT = -.658V-.390I+.0337VI+24.410$
Analogy	$X2 = 1$	$MOQT = .619V+.394I-.0295VI+8.949$
Diagram	$X1 = 1$	$MOQT = .241V+.243I-.0180VI+14.361$
Factor-Label	$X3 = X2 = X1 = -1$	$MOQT = -.285V-.0738I+.0133VI+19.276$

Table 28

Moles Immediate Posttest (MOQT): Substitution of Extreme Values for VVQV (1 → 30) and VVQI (2 → 23)

VVQV		VVQI		VI		TREATMENT		PREDICTED MOQT
1	-.66	2	-.78	2	.07	P	24.410	23.04
30	-.20	2	-.78	60	2.02	P	24.410	5.91
1	-.66	23	-8.97	23	.08	P	24.410	14.86
30	-.20	23	-8.97	690	23.25	P	24.410	18.95
1	.62	2	.79	2	-.06	A	8.949	10.30
30	18.57	2	.79	60	-1.77	A	8.949	26.54
1	.62	23	9.06	23	-.68	A	8.949	17.95
30	18.57	23	9.06	690	-20.36	A	8.949	16.23
1	.24	2	.49	2	-.04	D	14.361	15.05
30	7.23	2	.49	60	-1.08	D	14.361	21.00
1	.24	23	5.59	23	-.41	D	14.361	19.78
30	7.23	23	5.59	690	-12.42	D	14.361	14.76
1	-.28	2	-.15	2	.03	F	19.276	18.87
30	-8.55	2	-.15	60	.80	F	19.276	11.38
1	-.28	23	-1.70	23	.31	F	19.276	17.60
30	-8.55	23	-1.70	690	9.18	F	19.276	18.21

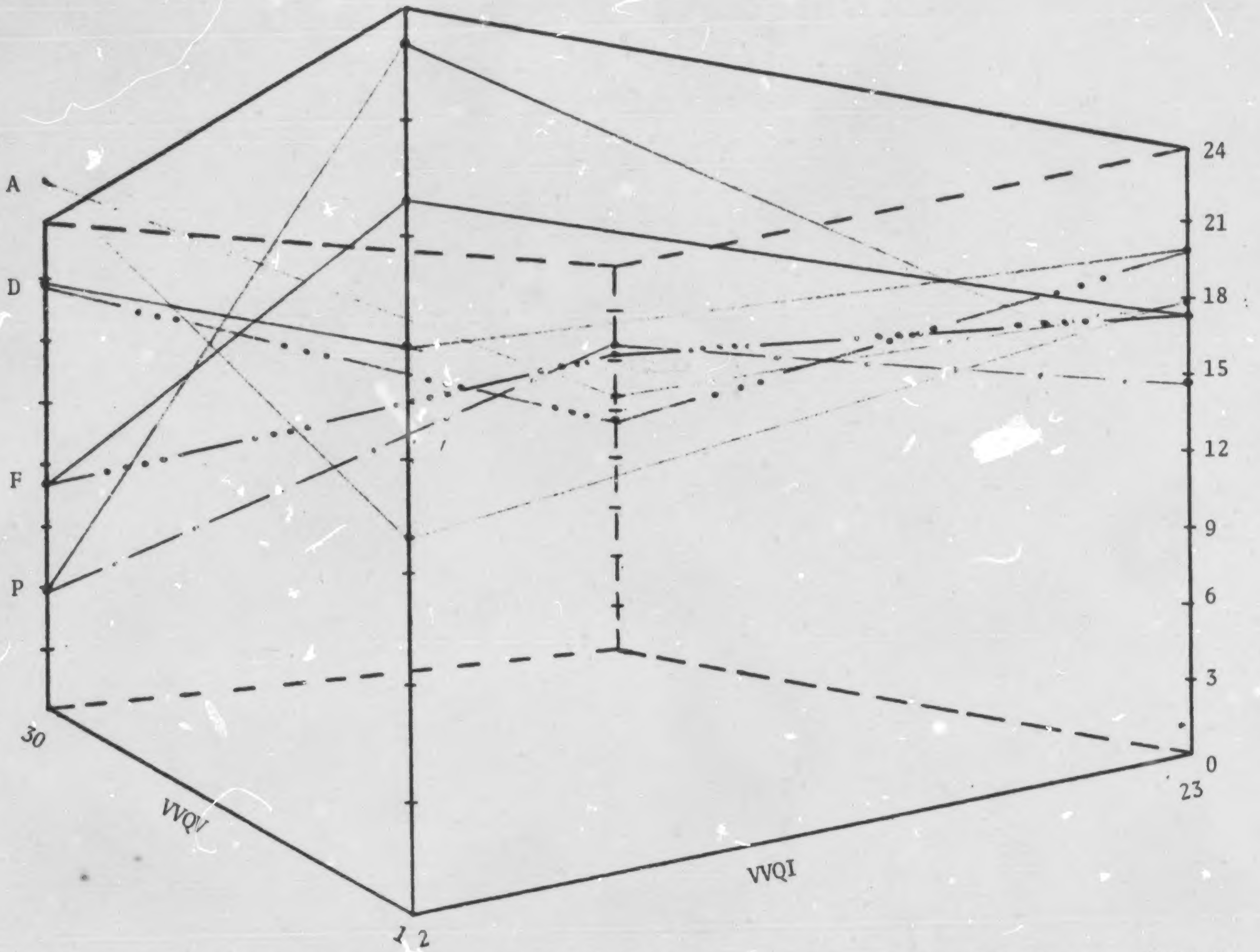

Figure 8. Moles Immediate Posttest (MOQT): Verbal Preference (VVQV) X Visual Preference (VVQI) X Treatment (X1-X3) Interaction

Table 29

Gas Laws Immediate Posttest (GLQT):

Verbal Preference (VVQV) X Visual Preference (VVQI) X

Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$GLQT = -.2663V - .1378I + .0134VI + 13.832$
Analogy	$X2 = 1$	$GLQT = .3623V + .2743I - .0190VI + 4.606$
Diagram	$X1 = 1$	$GLQT = .0362V - .00778I - .00121VI + 10.525$
Factor-Label	$X3 = X2 = X1 = -1$	$GLQT = -.1820V - .00908I + .00686VI + 11.229$

Table 30

Gas Laws Immediate Posttest (GLQT): Substitution of Extreme Values for VVQV (1 → 30) and VVQI (2 → 23)

VVQV		VVQI		VI		TREATMENT		PREDICTED GLQT
1	-.27	2	-.28	2	.03	P	13.832	13.32
30	-7.99	2	-.28	60	.80	P	13.832	6.37
1	-.27	23	-3.17	23	.31	P	13.832	10.70
30	-7.99	23	-3.17	690	9.25	P	13.832	11.92
1	.36	2	.55	2	-.04	A	4.606	5.48
30	10.87	2	.55	60	-1.14	A	4.606	14.88
1	.36	23	6.31	23	-.44	A	4.606	10.84
30	10.87	23	6.31	690	-13.11	A	4.606	8.67
1	.04	2	-.02	2	-.00	D	10.525	10.54
30	1.09	2	-.02	60	-.07	D	10.525	11.52
1	.04	23	-.18	23	-.03	D	10.525	10.35
30	1.09	23	-.18	690	-.83	D	10.525	10.60
1	-.18	2	-.02	2	.01	F	11.229	11.04
30	-5.46	2	-.02	60	.41	F	11.229	6.16
1	-.18	23	-.21	23	.16	F	11.229	11.00
30	-5.46	23	-.21	690	4.73	F	11.229	10.29

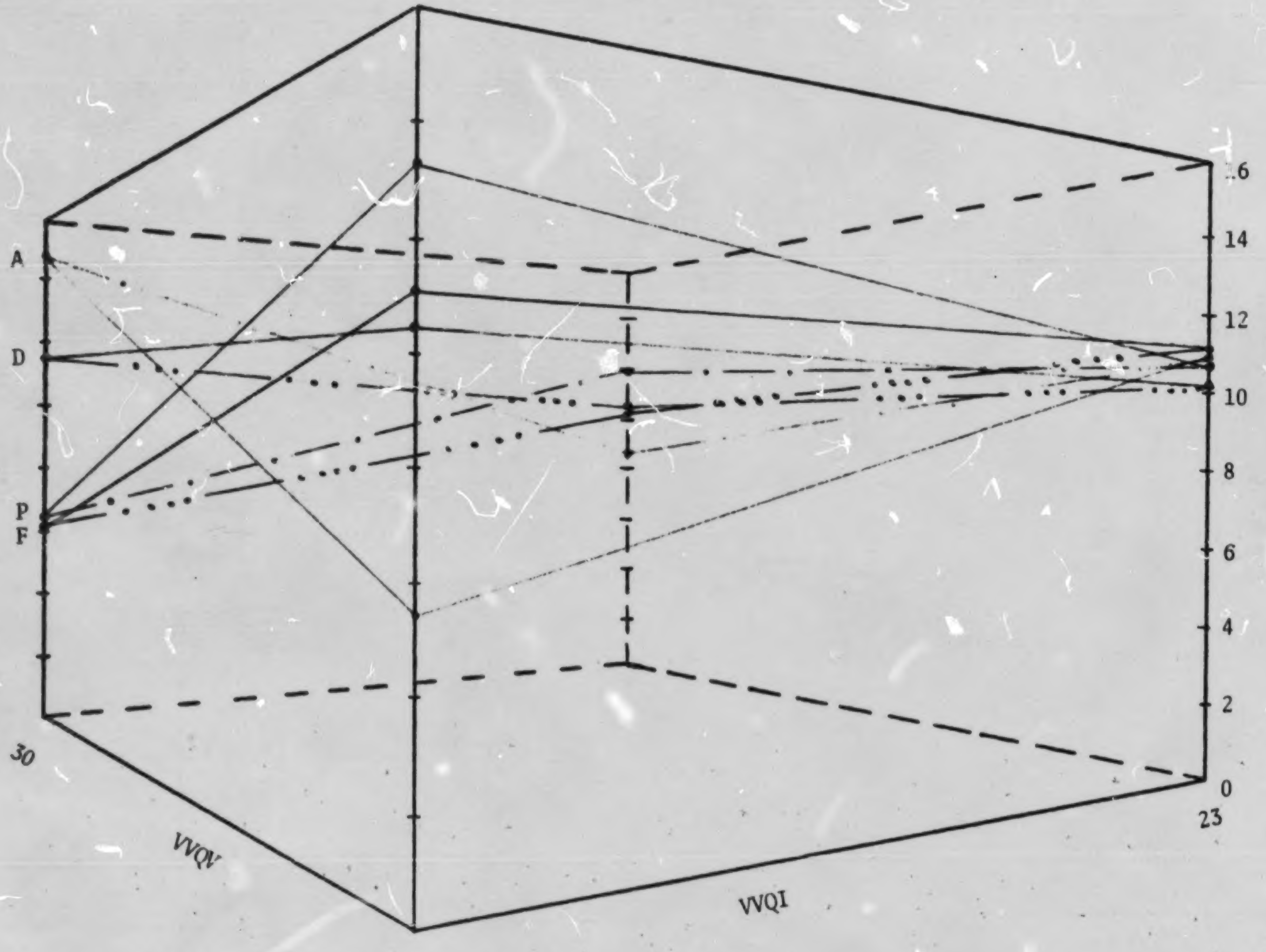

Figure 9. Gas Laws Immediate Posttest (GLQT): Verbal Preference (VVQV) X Visual Preference (VVQI) X Treatment (X1-X3) Interaction

Table 31

Stoichiometry Immediate Posttest (SQT):

Verbal Preference (VVQV) X Visual Preference (VVQI) X

Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$SQT = +.0704V+.0795I-.00361VI+7.529$
Analogy	$X2 = 1$	$SQT = -.211V-.128I+.00945VI+12.179$
Diagram	$X1 = 1$	$SQT = -.110V-.0316I+.00435VI+10.379$
Factor-Label	$X3 = X2 = X1 = -1$	$SQT = +.190V+.231I-.0108VI+5.605$

Table 32

Stoichiometry Immediate Posttest (SQT):
Substitution of Extreme Values for
VVQV (1 → 30) and VVQI (2 → 23)

VVQV		VVQI		VI		TREATMENT		PREDICTED SQT
1	.07	2	.16	2	-.01	P	7.529	7.75
30	2.11	2	.16	60	-.18	P	7.529	9.62
1	.07	23	1.83	23	-.07	P	7.529	9.36
30	2.11	23	1.83	690	-2.08	P	7.529	9.39
1	-.21	2	-.26	2	.02	A	12.179	11.73
30	-6.33	2	-.26	60	.57	A	12.179	6.16
1	-.21	23	-2.94	23	.22	A	12.179	9.24
30	-6.33	23	-2.94	690	6.52	A	12.179	9.43
1	-.11	2	-.06	2	.01	D	10.379	10.21
30	-3.30	2	-.06	60	.26	D	10.379	7.28
1	-.11	23	-.73	23	.10	D	10.379	9.64
30	-3.30	23	-.73	690	3.00	D	10.379	9.35
1	.19	2	.46	2	-.02	F	5.605	6.24
30	5.70	2	.46	60	-.65	F	5.605	11.12
1	.19	23	5.31	23	-.25	F	5.605	10.86
30	5.70	23	5.31	690	-7.45	F	5.605	9.17

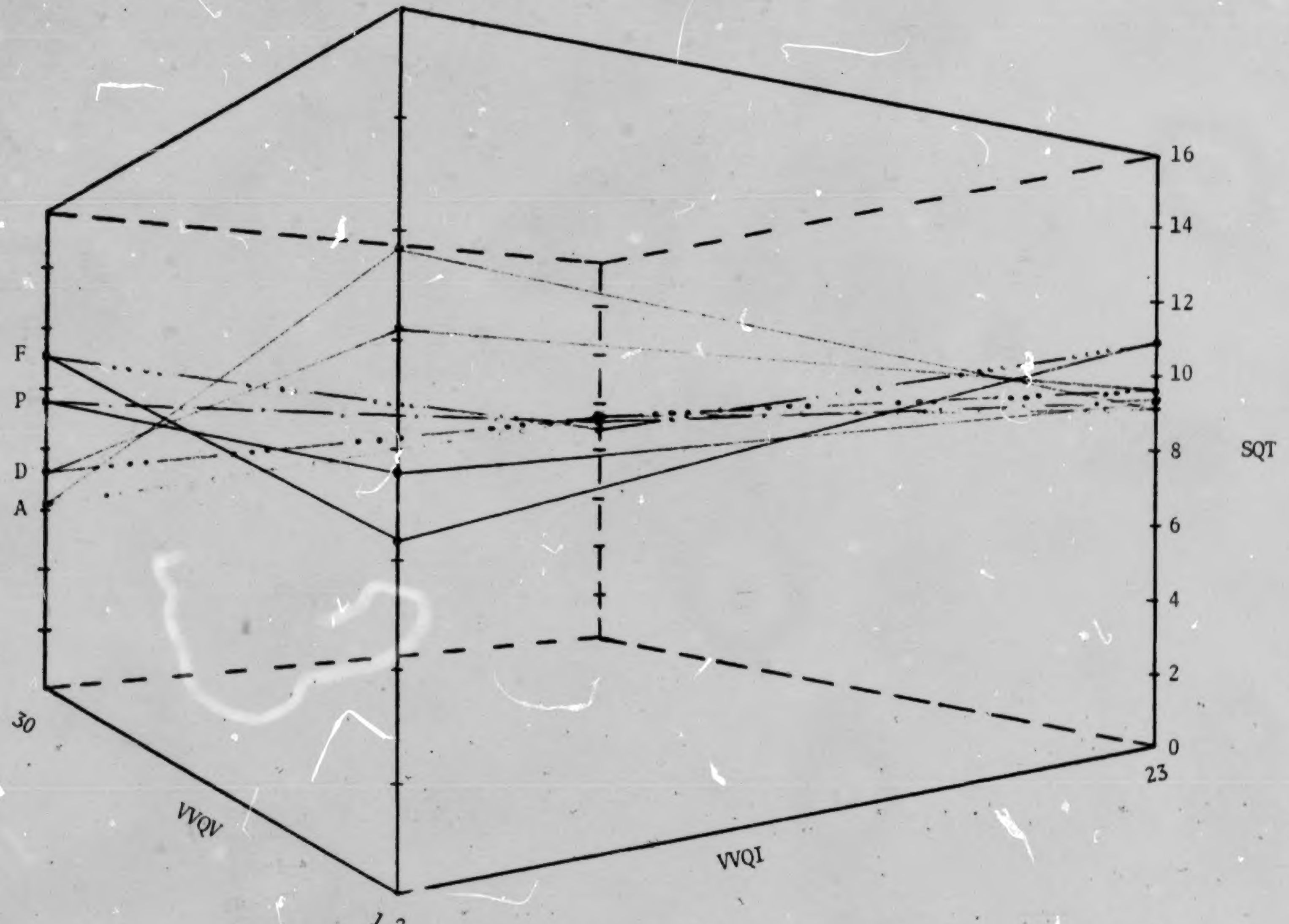

Figure 10. Stoichiometry Immediate Posttest (SQT): Verbal Preference (VVQV) X Visual Preference (VVQI) X Treatment (X1-X3) Interaction

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Table 33

Molarity Immediate Posttest (MLQT):

Verbal Preference (VVQV) X Visual Preference (VVQI) X

Treatment (X1-X3) Interaction

Stragety	Dummy Variables	Equation
Proportion	$X3 = 1$	$MLQT = .1347V+.3183I-.00781VI+5.178$
Analogy	$X2 = 1$	$MLQT = .2689V+.3513I-.0133VI+4.448$
Diagram	$X1 = 1$	$MLQT = -.0614V+.0710I-.000360VI+11.228$
Factor-Label	$X3 = X2 = X1 = -1$	$MLQT = -.4059V-.2767I+.0214VI+16.968$

Table 34

Molarity Immediate Posttest (MLQT):

Substitution of Extreme Values for

VVQV (1→30) and VVQI (2→23)

VVQV		VVQI		VI		TREATMENT		PREDICTED MLQT
1	.13	2	.64	2	-.02	P	5.178	5.93
30	4.04	2	.64	60	-.47	P	5.178	9.39
1	.13	23	7.32	23	-.18	P	5.178	12.45
30	4.04	23	7.32	690	-5.39	P	5.178	11.15
1	.27	2	.70	2	-.03	A	4.448	5.39
30	8.07	2	.70	60	-.80	A	4.448	12.42
1	.27	23	8.08	23	-.31	A	4.448	12.49
30	8.07	23	8.08	690	-9.18	A	4.448	11.42
1	-.06	2	.14	2	-.00	D	11.228	11.31
30	-1.84	2	.14	60	-.02	D	11.228	9.51
1	-.06	23	1.63	23	-.01	D	11.228	12.79
30	-1.84	23	1.63	690	-.25	D	11.228	10.77
1	-.41	2	-.55	2	.04	F	16.968	16.05
30	-12.18	2	-.55	60	1.28	F	16.968	5.52
1	-.41	23	-6.36	23	.49	F	16.968	10.69
30	-12.18	23	-6.36	690	14.77	F	16.968	13.19

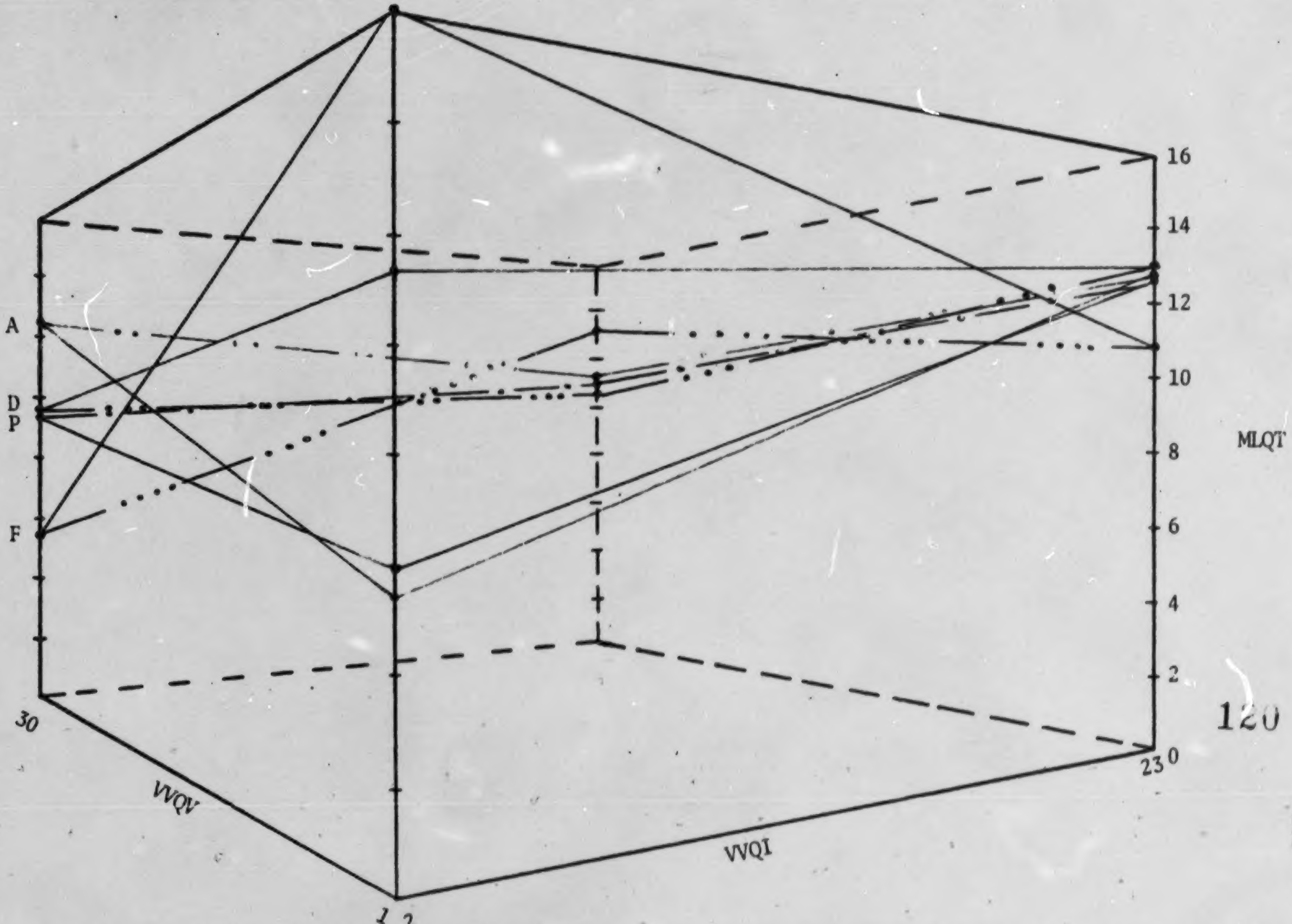

Figure 11. Molarity Immediate Posttest (MLQT): Verbal Preference (VVQV) X Visual Preference (VVQI) X Treatment (X1-X3) Interaction

Table 35

Stoichiometry Immediate Posttest (SQT): General Regression Equation

$$\begin{aligned}
\text{SQT} = {} & -.0140(\text{V}) + .0375(\text{I}) - .00757(\text{MARSTOT}) + .1281(\text{PPRT}) + \\
& 35.892(\text{X3}) - 27.270(\text{X2}) - 23.524(\text{X1}) + .8876(\text{VX2}) - .6725 \\
& (\text{VX1}) - 1.498(\text{VX3}) - 1.773(\text{IX3}) + 1.146(\text{IX2}) + 1.559(\text{IX1}) \\
& + 1431(\text{MX1}) - .2327(\text{MX3}) + .1380(\text{MX2}) + 3.031(\text{PX2}) + 1.158 \\
& (\text{PX1}) - 3.296(\text{PX3}) + .00679(\text{VIX1}) + .0728(\text{VIX3}) - .0335 \\
& (\text{VIX2}) + .000240(\text{VMX1}) - .00167(\text{VMX2}) + .0104(\text{VMX3}) - \\
& .00993(\text{IMX1}) + .0116(\text{IMX3}) - .00595(\text{IMX2}) - .1304(\text{VPX2}) \\
& + .0623(\text{VPX1}) + .1508(\text{VPX3}) - .0926(\text{IPX1}) + .1539(\text{IPX3}) \\
& - .1269(\text{IPX2}) - .00689(\text{PMX1}) - .0142(\text{PMX2}) + .0203(\text{PMX3}) \\
& + .000181(\text{VIMX1}) - .000522(\text{VIMX3}) + .0000243(\text{VIMX2}) - \\
& .000746(\text{VIPX1}) + .00536(\text{VIPX2}) - .00702(\text{VIPX3}) - .000109 \\
& (\text{VPMX1}) + .000373(\text{VPMX2}) - .000965(\text{VPMX3}) + .000590 \\
& (\text{IPMX1}) + .000596(\text{IMPX2}) - .000976(\text{IMPX3}) - .0000114 \\
& (\text{VIPMX1}) - .0000125(\text{VIMPX2}) + .0000469(\text{VIMPX3}) + 8.704
\end{aligned}$$

Where $\overline{\text{VVQV}}\ (\bar{\text{V}}) = 15.807$ $\quad\overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}\ (\bar{\text{I}}) = 18.020$ $\quad\overline{\text{PPRT}} = 12.614$

Table 36

Stoichiometry Immediate Posttest (SQT): Main Effects Regression Equation

Equation: SQT = -.00545 (MARSTOT) + .152 (PPRT) + .8546

Table 37

Stoichiometry Immediate Posttest (SQT): F Tests for Possible Significant Effects

Mean = 9.451 S.D. = 2.376 Cases = 528 Max. = 12

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.02436	.02436/.001774[a] = 13.73	.01
PPRT	.07245	.07245/.001774 = 40.84	.01
IMX1 IMX3 IMX2	.01257 .00000 .00799 .02056	$\frac{.02056/_3}{.001774} = 3.86$	.05
IMX1	.01257	.01257/.001774 = 7.08	.01
IMX3	.00000	-	NS[b]
IMX2	.00799	.00799/.001774 = 4.5	.05
VPMX1 VPMX2 VPMX3	.00627 .00170 .00075 .00872	$\frac{.00872/_3}{.001774} = 1.64$	NS

---

[a] Error Term = (1-.18404)/475-15 = .001774

[b] NS = Nonsignificant

Table 38

Stoichiometry Immediate Posttest (SQT): Calculations for "Fourth" Effect

Visual X Math Anxiety X Treatment Interaction

Effect	B	S.E.B.
IMX1	-.00162	.000968
IMX3	+.000663	.00100
IMX2	-.00223	.00103

$$B_4 = -\Sigma B_i = -(-.00162 + .000663 - .00223) = .003187$$

$$S.E.B._4 = \Sigma \frac{S.E.B._i}{3} = \frac{.000968 + .00100 + .00103}{3} = .000999$$

$$t_4 = \frac{B_4}{S.E.B._4} = \frac{.003187}{.000999} = 3.19 \qquad p < .01$$

Table 39

Stoichiometry Immediate Posttest (SQT):
Visual Preference (VVQI) X Mathematics Anxiety (M) X
Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$SQT = -.0425I-.0121M+.00040IM+10.844$
Analogy	$X2 = 1$	$SQT = .121I-.00057M-.000882IM+9.177$
Diagram	$X1 = 1$	$SQT = .387I+.0306M-.00190IM+2.981$
Factor-Label	$X3 = X2 = X1 = -1$	$SQT = -.314I-.0482M+.00202IM+17.527$

Table 40

Stoichiometry Immediate Posttest (SQT):

Substitution of Extreme Values for

VVQI (2 → 23) and MARSTOT (101 → 349)

VVQI		MARSTOT		IM		TREATMENT		PREDICTED SQT
2	-.08	101	-1.22	202	.08	P	10.844	9.62
23	-.98	101	-1.22	2323	.93	P	10.844	9.57
2	-.08	349	-4.22	698	.28	P	10.844	6.82
23	-.98	349	-4.22	8027	3.21	P	10.844	8.85
2	.24	101	-.06	202	-.18	A	9.177	9.18
23	2.78	101	-.06	2323	-2.05	A	9.177	9.85
2	.24	349	-.20	698	-.62	A	9.177	8.60
23	2.78	349	-.20	8027	-7.08	A	9.177	4.68
2	.77	101	3.09	202	-.38	D	2.981	6.46
23	8.90	101	3.09	2323	-4.41	D	2.981	10.56
2	.77	349	10.68	698	-1.33	D	2.981	13.11
23	8.90	349	10.68	8027	-15.25	D	2.981	7.31
2	-.63	101	-4.87	202	.41	F	17.527	12.44
23	-7.22	101	-4.87	2323	4.69	F	17.527	10.13
2	-.63	349	-16.82	698	1.41	F	17.527	1.49
23	-7.22	349	-16.82	8027	16.21	F	17.527	9.70

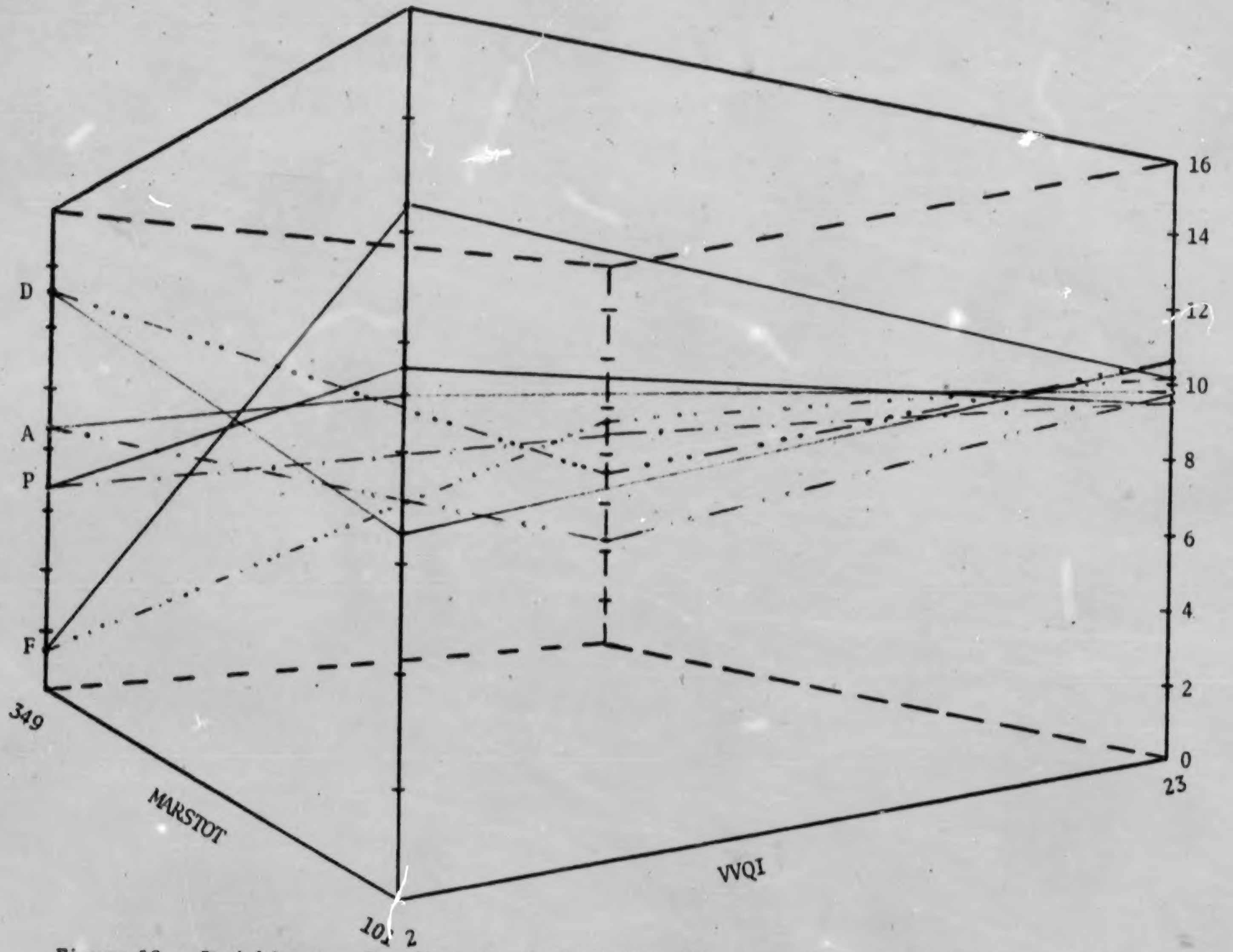

Figure 12. Stoichiometry Immediate Posttest (SQT): Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Table 41

Moles Immediate Posttest (MOQT):

Visual Preference (VVQI) X Mathematics Anxiety (M) X

Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$MOQT = -.3045I - .0458M + .00234IM + 22.354$
Analogy	$X2 = 1$	$MOQT = .1100I + .0150M - .000992IM + 15.971$
Diagram	$X1 = 1$	$MOQT = .4447I + .0377M - .00263IM + 11.313$
Factor-Label	$X3 = X2 = X1 = -1$	$MOQT = -.0928I - .0376M + .00128IM + 21.592$

Table 42

Moles Immediate Posttest (MOQT):

Substitution of Extreme Values for

VVQI (2 → 23) and MARSTOT (101 → 349)

VVQI		MARSTOT		IM		TREATMENT		PREDICTED MOQT
2	-.61	101	-4.63	202	.47	P	22.354	17.59
23	-7.00	101	-4.63	2323	5.44	P	22.354	16.16
2	-.61	349	-15.98	698	1.63	P	22.354	7.39
23	-7.00	349	-15.98	8027	18.78	P	22.354	18.15
2	.22	101	1.52	202	-.20	A	15.971	17.51
23	2.53	101	1.52	2323	-2.30	A	15.971	17.71
2	.22	349	5.24	698	-.69	A	15.971	20.73
23	2.53	349	5.24	8027	-7.96	A	15.971	15.77
2	.89	101	3.81	202	-.53	D	11.313	15.48
23	10.23	101	3.81	2323	-6.11	D	11.313	19.24
2	.89	349	13.16	698	-1.84	D	11.313	23.52
23	10.23	349	13.16	8027	-21.11	D	11.313	13.59
2	-.19	101	-3.80	202	.26	F	21.592	17.87
23	-2.13	101	-3.80	2323	2.97	F	21.592	18.63
2	-.19	349	-13.12	698	.89	F	21.592	9.18
23	-2.13	349	-13.12	8027	16.27	F	21.592	16.61

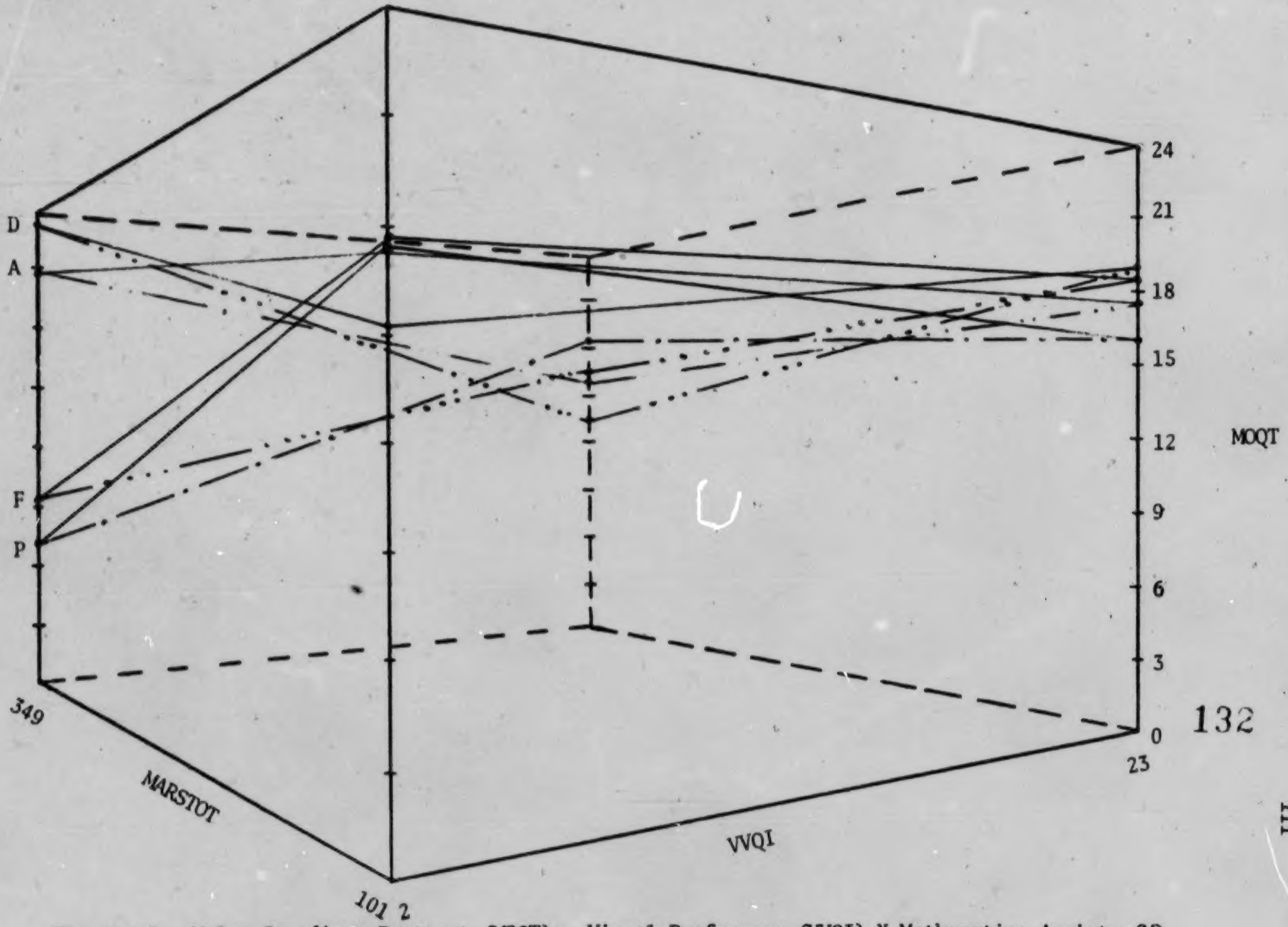

Figure 13. Moles Immedi[illegible]e Posttest (MOQT): Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Table 43

Gas Laws Immediate Posttest (GLQT): Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Stragegy	Dummy Variables	Equation
Proportion	$X3 = 1$	$GLQT = .00588I - .00504M + .000043\ IM + 10.548$
Analogy	$X2 = 1$	$GLQT = -.1389I - .0106M + ,000282IM + 12.282$
Diagram	$X1 = 1$	$GLQT = .0417I + .0124M - .000697IM + 8.020$
Factor-Label	$X3 = X2 = X1 = -1$	$GLQT = -.0277I - .0174M + .000364IM + 11.562$

Table 44

Gas Laws Immediate Posttest (GLQT):
Substitution of Extreme Values for
VVQI (2 → 23) and MARSTOT (101 → 349)

VVQI		MARSTOT		IM		TREATMENT		PREDICTED GLQT
2	.01	101	-.51	202	.01	P	10.548	10.06
23	.14	101	-.51	2323	.10	P	10.548	10.27
2	.01	349	-1.76	698	.03	P	10.548	8.83
23	.14	349	-1.76	8027	.35	P	10.548	9.27
2	-.28	101	-1.07	202	.06	A	12.282	10.99
23	-3.19	101	-1.07	2323	.66	A	12.282	8.67
2	-.28	349	-3.70	698	.20	A	12.282	8.50
23	-3.19	349	-3.70	8027	2.26	A	12.282	7.65
2	.08	101	1.25	202	-14.08	D	8.020	9.22
23	.96	101	1.25	2323	-1.62	D	8.020	8.61
2	.08	349	4.33	698	-.49	D	8.020	11.94
23	.96	349	4.33	8027	-5.59	D	8.020	7.71
2	-.06	101	-1.76	202	.07	F	11.562	9.82
23	-.64	101	-1.76	2323	.85	F	11.562	10.01
2	.06	349	-6.07	698	.25	F	11.562	5.69
23	-.64	349	-6.07	8027	2.92	F	11.562	7.77

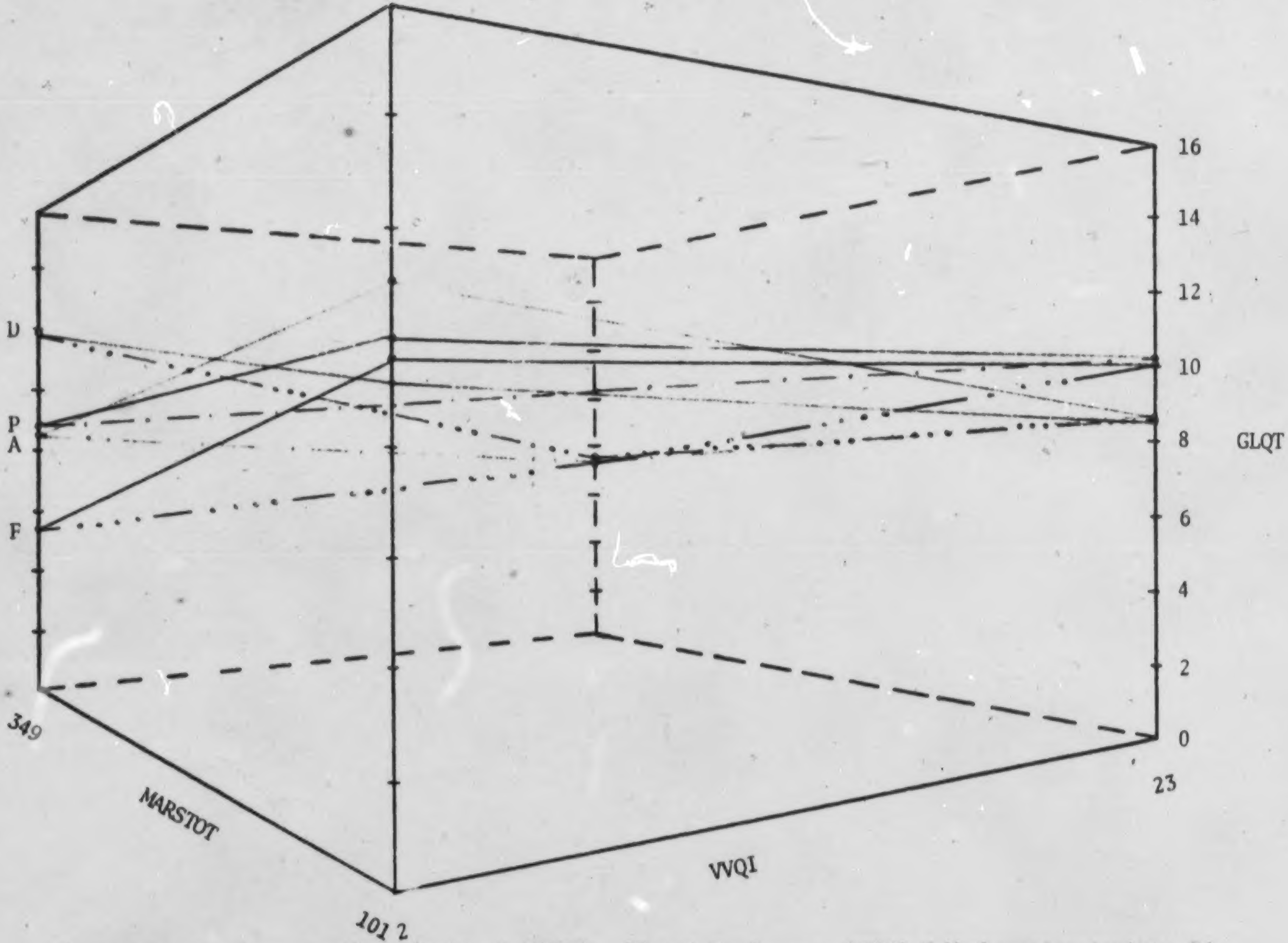

Figure 14. Gas Laws Immediate Posttest (GLQT): Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Table 45

Molarity Immediate Posttest (MLQT): Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$MLQT = -.6175I-.0841M+.00440IM+22.815$
Analogy	$X2 = 1$	$MLQT = .1973I-.00474M-.000308IM+9.577$
Diagram	$X1 = 1$	$MLQT = .7506I+.0628M-.00371IM-1.321$
Factor-Label	$X3 = X2 = X1 = -1$	$MLQT = .1188I+.00378M-.000311IM+9.851$

Table 46

Molarity Immediate Posttest (MLQT):

Substitution of Extreme Values for

VVQI (2 → 23) and MARSTOT (101 → 349)

VVQI		MARSTOT		IM		TREATMENT		PREDICTED MLQT
2	-1.24	101	-8.49	202	.89	P	22.815	13.97
23	-14.20	101	-8.49	2323	10.22	P	22.815	10.31
2	-1.24	349	-29.35	698	3.07	P	22.815	-4.70
23	-14.20	349	-29.35	8027	35.32	P	22.815	14.58
2	.39	101	-.48	202	-.06	A	9.577	9.43
23	4.54	101	-.48	2323	-.72	A	9.577	12.92
2	.39	349	-1.65	698	-.21	A	9.577	8.10
23	4.54	349	-1.65	8027	-2.47	A	9.577	9.99
2	1.50	101	6.34	202	-.75	D	-1.321	5.77
23	17.26	101	6.34	2323	-8.62	D	-1.321	13.68
2	1.50	349	21.92	698	-2.59	D	-1.321	19.51
23	17.26	349	21.92	8027	-29.78	D	-1.321	8.08
2	.24	101	.38	202	-.06	F	9.851	10.41
23	2.73	101	.38	2323	-.72	F	9.851	12.24
2	.24	349	1.32	698	-.22	F	9.851	11.19
23	2.73	349	1.32	8027	-2.50	F	9.851	11.41

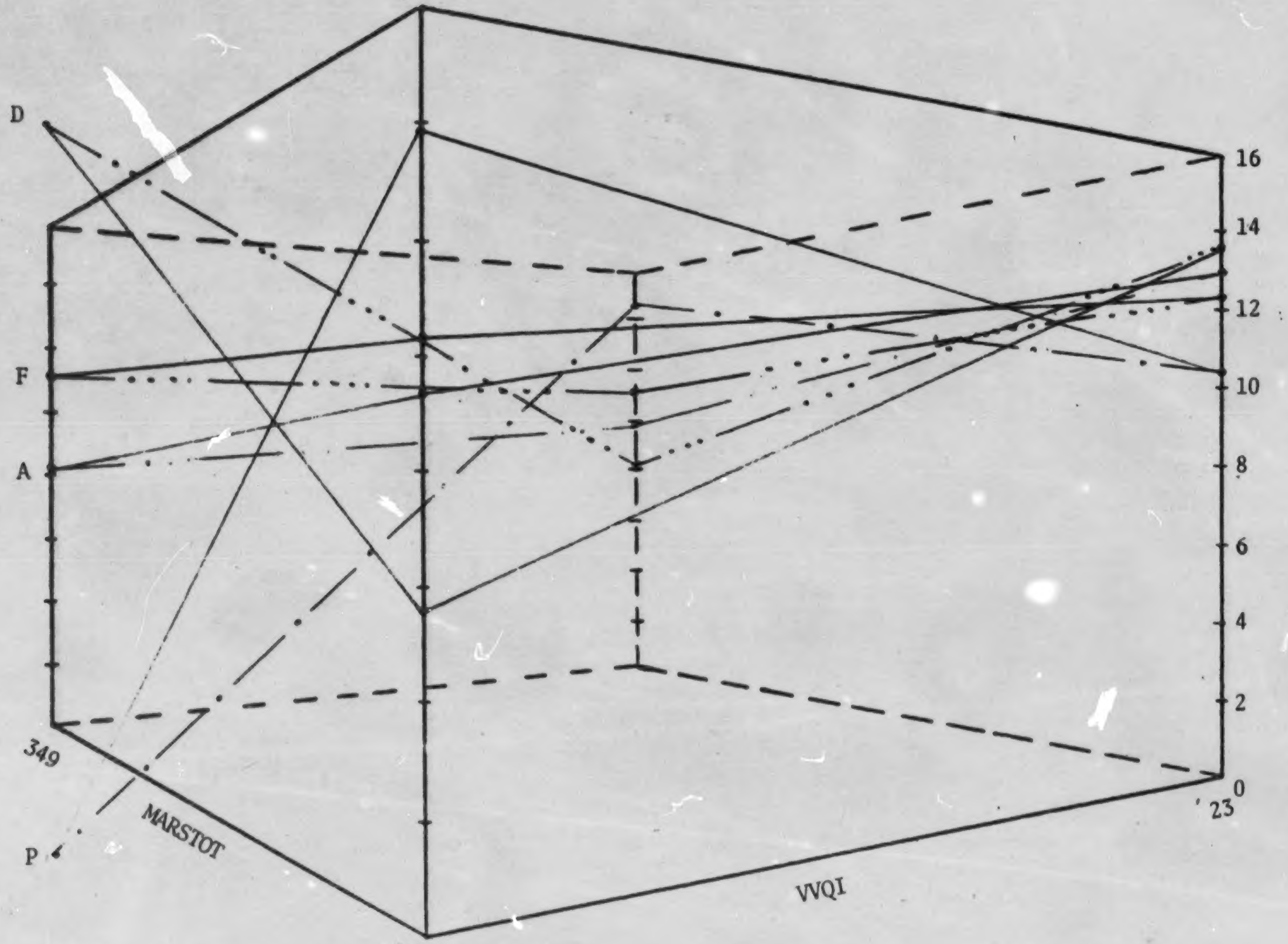

Figure 15. Molarity Immediate Posttest (MLQT): Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Table 47

Decimal Subtest (DE): General Regression Equation

$$\begin{aligned}
\text{DE} = {} & -.0130(\text{V}) + .0575(\text{I}) - .00513(\text{MARSTOT} + .1197(\text{PPRT}) \\
& - 1.627(\text{X2}) - 20.657(\text{X1}) + 31.369(\text{X3}) - 2.010(\text{VX2}) - \\
& .4212(\text{VX3}) + 1.391(\text{VX1}) - 1.751(\text{IX3}) + 1.059(\text{IX1}) + \\
& .5485(\text{IX2}) + .0884(\text{MX1}) - .1890(\text{MX3}) + .0146(\text{MX2}) + \\
& .7302(\text{PX2}) + .0350(\text{PX1}) - 2.808(\text{PX3}) - .0750(\text{VIX1}) + \\
& .0176(\text{VIX3}) + .0882(\text{VIX2}) - .00523(\text{VMX1}) + .0108(\text{VMX2}) \\
& + .00155(\text{VMX3}) + .0108(\text{IMX3}) - .00523(\text{IMX1}) - .00306(\text{IMX2}) \\
& + .0939(\text{VPX2}) - .0512(\text{VPX1}) + .0987(\text{VPX3}) - .00427(\text{IPX1}) \\
& + .1535(\text{IPX3}) - .0643(\text{IPX2}) + .00181(\text{PMX1}) - .00637(\text{PMX2}) \\
& + .0183(\text{PMX3}) + .000317(\text{VIMX1}) - .0000797(\text{VIMX3}) - .000480 \\
& (\text{VIMX2}) + .00301(\text{VIPX1}) - .00396(\text{VIPX2}) - .00475(\text{VIPX3}) + \\
& .000125(\text{VPMX1}) - .000373(\text{VPMX2}) - .000598(\text{VPMX3}) + \\
& .000447(\text{IPMX2}) - .0000116(\text{IPMX1}) - .00101(\text{IPMX3}) + .0000155 \\
& (\text{VIPMX2}) - .0000117(\text{VIPMX1}) + .0000301(\text{VIPMX3}) + 9.397
\end{aligned}$$

Where $\overline{\text{VVQV}}\ (\overline{\text{V}}) = 15.807$ $\qquad \overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}\ (\overline{\text{I}}) = 18.020$ $\qquad \overline{\text{PPRT}} = 12.614$

Table 48

Decimal Subtest (DE): F Tests for Possible Significant Effects

Mean = 10.815 S.D. = 1.903 Cases = 421 Max. = 13

Predictor	ΔR^2	F	Sig.Level
VVQI	.01035	.01035/.002120[a]= 4.88	.05
MARSTOT	.02232	.02232/.002120 = 10.53	.01
PPRT	.07421	.07421/.002120 = 35.00	.01
IMX3 IMX1 IMX2	.00004 .01603 .00294 .01901	$\frac{.01901/3}{.002120} = 2.99$	.05
IMX3	.00004	.00004/.002120 = .02	NS[b]
IMX1	.01603	.01603/.002120 = 7.56	.01
IMX2	.00294	.00294/.002120 = 1.39	NS
IPMX2 IPMX1 IPMX3	.00577 .00432 .00657 .01666	$\frac{.01666/3}{.002120} = 2.62$	NS

---

[a] Error Term = (1-.21969)/368 = .002120

[b] NS = Nonsignificant

Table 49

Decimal Subtest (DE): Calculations for "Fourth" Effect

Visual X Math Anxiety X Treatment Interaction

Effect	B	S.E.B.
IMX3	+.00172	.000966
IMX1	-.00207	.000961
IMX2	-.00128	.00108

$B_4 = \Sigma B_i = (.00172 - .00207 - .00128) = .00163$

$S.E.B._4 = \Sigma \frac{S.E.B._i}{3} = \frac{.000966 + .000961 + .00108}{3} = .001002$

$t_4 = \frac{B_4}{S.E.B._4} = \frac{.00163}{.001002} = 1.63$ NS

Table 50

Decimal Subtest (DE): Main Effects Regression Equation

Equation: $DE = .0372\ (VVQI) - .00421\ (MARSTOT + .124\ (PPRT) + 9.513$

Table 51

Decimal Subtest (DE):

Visual Preference (VVQI) X Mathematics Anxiety (M) X

Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$DE = -.4260I - .0583M + .00277IM + 19.679$
Analogy	$X2 = 1$	$DE = .4005I + .0250M - .00189IM + 5.223$
Diagram	$X1 = 1$	$DE = .4778I + .0484M - .00270IM + 2.277$
Factor-Label	$X3 = X2 = X1 = -1$	$DE = -.2222I - .0356M + .00116IM + 15.634$

Table 52

Decimal Subtest (DE):

Substitution of Extreme Values for

VVQI (2 →23) and MARSTOT (101 →349)

V VQI		MARSTOT		IM		TREATMENT		PREDICTED DE
2	-.85	101	-5.89	202	.56	P	19.679	13.50
23	-9.80	101	-5.89	2323	6.43	P	19.679	10.43
2	-.85	349	-20.35	698	1.93	P	19.679	.41
23	-9.80	349	-20.35	8027	22.23	P	19.679	11.77
2	.80	101	2.52	202	-.38	A	5.223	8.17
23	9.21	101	2.52	2323	-4.39	A	5.223	12.57
2	.80	349	8.72	698	-1.32	A	5.223	13.43
23	9.21	349	8.72	8027	-15.17	A	5.223	7.80
2	.96	101	4.89	202	-.55	D	2.277	7.58
23	10.99	101	4.89	2323	-6.27	D	2.277	11.88
2	.96	349	16.89	698	-1.88	D	2.277	18.28
23	10.99	349	16.89	8027	-21.67	D	2.277	8.49
2	-.44	101	-3.60	202	.23	F	15.634	11.83
23	-5.11	101	-3.60	2323	2.69	F	15.634	9.62
2	-.44	349	-12.42	698	.81	F	15.634	3.57
23	-5.11	349	-12.42	8027	9.31	F	15.634	7.41

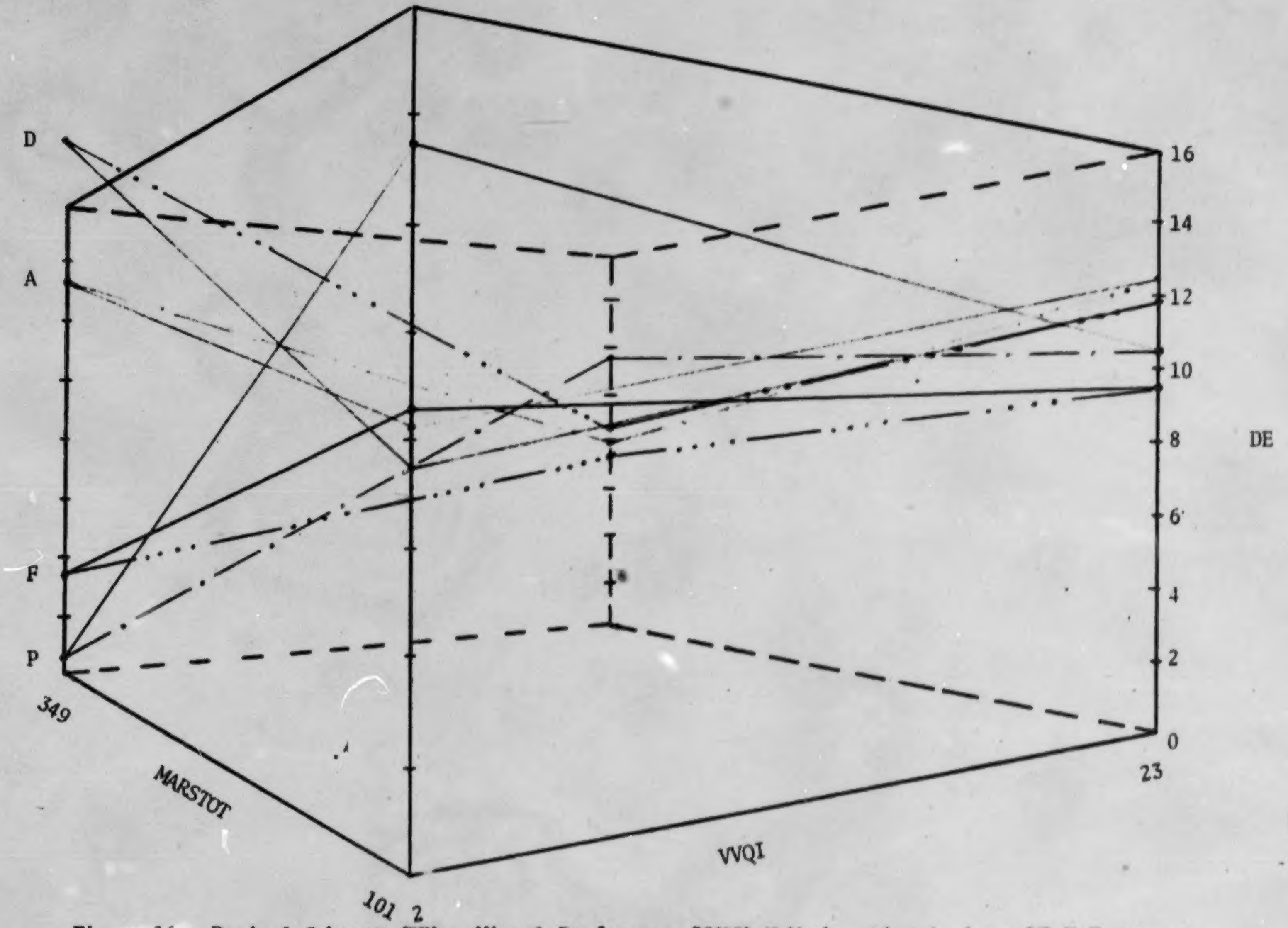

Figure 16. Decimal Subtest (DE): Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Table 53

Nondecimal Subtest (NDE): General Regression Equation

$$
\begin{aligned}
\text{NDE} = {} & -.0271(\text{V}) + .0427(\text{I}) - .00484(\text{MARSTOT}) + .0812(\text{PPRT}) \\
& - 16.238(\text{X2}) - 36.544(\text{X1}) + 33.824(\text{X3}) + .1191(\text{VX2}) - \\
& 2.030(\text{VX3}) + 2.395(\text{VX1}) - 2.058(\text{IX3}) + 2.184(\text{IX1}) + \\
& .8566(\text{IX2}) + .1883(\text{MX1}) - .2163(\text{MX3}) + .1124(\text{MX2}) + \\
& .9716(\text{PX2}) + 2.420(\text{PX1}) - 2.627(\text{PX3}) - .1479(\text{VIX1}) + \\
& .1238(\text{VIX3}) - .00758(\text{VIX2}) + .0144(\text{VMX1}) - .00279(\text{VMX2}) \\
& - .0136(\text{VMX3}) + .0133(\text{IMX3}) - .0121(\text{IMX1}) - .00591(\text{IMX2}) \\
& + .00599(\text{VPX2}) - .1803(\text{VPX1}) + .1637(\text{VPX3}) - .1466(\text{IPX1}) \\
& + .1538(\text{IPX3}) - .0511(\text{IPX2}) - .0123(\text{PMX1}) - .00774(\text{PMX2}) \\
& + .0170(\text{PMX3}) - .000881(\text{VIMX3}) + .000888(\text{VIMX1}) + .000154 \\
& (\text{VIMX2}) + .0111(\text{VIPX1}) - .000176(\text{VIPX2}) - .00964(\text{VIPX3}) \\
& + .00105(\text{VPMX1}) + .000178(\text{VPMX2}) - .00118(\text{VPMX3}) + .000404 \\
& (\text{IPMX2}) + .000816(\text{IPMX1}) - .00101(\text{IPMX3}) - .0000102(\text{VIPMX2}) \\
& - .0000686(\text{VIPMX1}) + .0000702(\text{VIPMX3}) + 10.838
\end{aligned}
$$

Where $\overline{\text{VVQV}}$ $(\overline{\text{V}}) = 15.807$ $\qquad \overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}$ $(\overline{\text{I}}) = 18.020$ $\qquad \overline{\text{PPRT}} = 12.614$

Table 54

Nondecimal Subtest (NDE): Main Effects Regression Equation

Equation: $NDE = .0376\ (VVQI) - .00450\ (MARSTOT) + .0854\ (PPRT) + 10.835$

Table 55

Nondecimal Subtest (NDE): F Tests for Possible Significant Effects

Mean = 11.322 S.D. = 1.477 Cases = 428 Max. = 13

Predictor	ΔR^2		Sig. Level
VVQI	.01331	.01331/.002140[a] = 6.22	.05
MARSTOT	.03641	.03641/.002140 = 17.01	.01
PPRT	.05837	.05837/.002140 = 27.28	.01
VPMX1	.00883	$\frac{.01120/3}{.002140} = 1.74$	NS[b]
VPMX2	.00105		
VPMX3	.00132		
	.01120		

---

[a] Error Term = (1-.19738)/375 = .002140

[b] NS = Nonsignificant

Table 56

Nondecimal Subtest (NDE):

Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$NDE = -.0396I-.0143M+.000619IM+12.665$
Analogy	$X2 = 1$	$NDE = .0996I+.00126M-.000404IM+10.527$
Diagram	$X1 = 1$	$NDE = .2542I+.0227M-.00146IM+7.331$
Factor-Label	$X3 = X2 = X1 = -1$	$NDE = -.1437I-.0291M+.00124IM+15.2111$

Table 57

Nondecimal Subtest (NDE): Substitution of Extreme Values for VVQI (2 → 23) and MARSTOT (101 → 349)

VVQI		MARSTOT		IM		TREATMENT		PREDICTED NDE
2	-.08	101	-1.44	202	.13	P	12.665	11.27
23	-.91	101	-1.44	2323	1.44	P	12.665	11.75
2	-.08	349	-4.99	698	.43	P	12.665	8.03
23	-.91	349	-4.99	8027	4.97	P	12.665	11.73
2	.20	101	.13	202	-.08	A	10.527	10.77
23	2.29	101	.13	2323	-.94	A	10.527	12.01
2	.20	349	.44	698	-.28	A	10.527	10.88
23	2.29	349	.44	8027	-3.24	A	10.527	10.01
2	.51	101	2.29	202	-.29	D	7.331	9.84
23	5.85	101	2.29	2323	-3.39	D	7.331	12.08
2	.51	349	7.92	698	-1.02	D	7.331	14.75
23	5.85	349	7.92	8027	-11.72	D	7.331	9.38
2	-.29	101	-2.94	202	.25	F	15.211	12.23
23	-3.31	101	-2.94	2323	2.88	F	15.211	11.85
2	-.29	349	-10.16	698	.87	F	15.211	5.63
23	-3.31	349	-10.16	8027	9.95	F	15.211	11.70

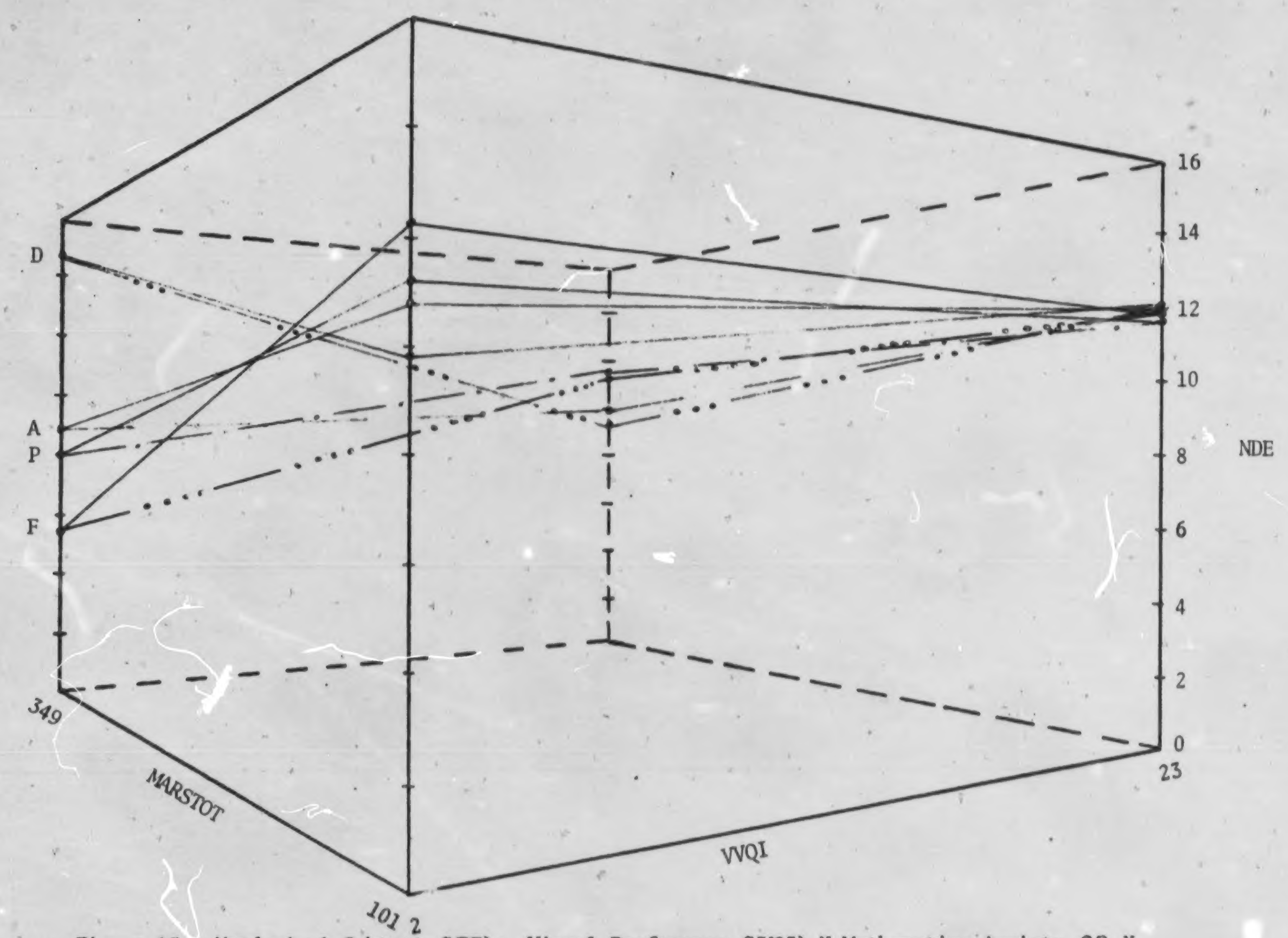

Figure 17. Nondecimal Subtest (NDE): Visual Preference (VVQI) X Mathematics Anxiety (M) X Treatment (X1-X3) Interaction

Table 58

Molarity Delayed Posttest (MLT): General Regression Equation

$$
\begin{aligned}
\text{MLT} = {} & -.00684(\text{V}) + .0109(\text{I}) - .00607(\text{MARSTOT}) + .1460(\text{PPRT}) \\
& + 30.440(\text{X3}) + 2.662(\text{X2}) - 27.920(\text{X1}) - .4202(\text{VX2}) + \\
& 1.320(\text{VX1}) - .8307(\text{VX3}) - .8477(\text{IX3}) + .0400(\text{IX2}) + \\
& 1.014(\text{IX1}) + .1153(\text{MX1}) - .2202(\text{MX3}) + .0498(\text{MX2}) - \\
& 1.320(\text{PX2}) + 1.491(\text{PX1}) - 1.326(\text{PX3}) - .0482(\text{VIX1}) \\
& + .00477(\text{VIX3}) + .00889(\text{VIX2}) - .00539(\text{VMX1}) - \\
& .000541(\text{VMX2}) + .00762(\text{VMX3}) - .00446(\text{IMX1}) + .00791 \\
& (\text{IMX3}) - .00278(\text{IMX2}) + .140(\text{VPX2}) - .0662(\text{VPX1}) \\
& + .0118(\text{VPX3}) - .0407(\text{IPX1}) + .0201(\text{IPX3}) + .0424(\text{IPX2}) \\
& - .00621(\text{PMX1}) + .000580(\text{PMX2}) + .0125(\text{PMX3}) + .000206 \\
& (\text{VIMX1}) - .000214(\text{VIMX3}) + .0000486(\text{VIMX2}) + .00145(\text{VIPX1}) \\
& - .00517(\text{VIPX2}) + .00164(\text{VIPX3}) + .000283(\text{VPMX1}) - \\
& .000417(\text{VPMX2}) - .000393(\text{VPMX3}) + .000195(\text{IPMX1}) + \\
& .0000494(\text{IPMX2}) - .000416(\text{IPMX3}) - .00000718(\text{VIPMX1}) + \\
& .000142(\text{VIPMX2}) + .00000970(\text{VIPMX3}) + 5.327
\end{aligned}
$$

Where $\overline{\text{VVQV}}\ (\overline{\text{V}}) = 15.807$ $\quad\overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}\ (\overline{\text{I}}) = 18.020$ $\quad\overline{\text{PPRT}} = 12.614$

Table 59

Molarity Delayed Posttest (MLT): Main Effects Regression Equation

Equation: $MLT = -.00552\ (MARSTOT) + .141\ (PPRT) + 5.786$

Table 60

Molarity Delayed Posttest (MLT): F Tests for Possible Significant Effects

Mean = 6.197 S.D. = 2.443 Cases = 481 Max. = 10

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.02314	.02314/.002150[a] = 10.80	.01
PPRT	.05945	.05945/.002150 = 27.65	.01
VMX1 VMX2 VMX3	.00026 .00725 $\underline{.00195}$ .00946	$\frac{.00946/_3}{.002150} = 1.47$	NS[b]
VPX2 VPX1 VPX3	.01149 .00566 $\underline{.00022}$ .01737	$\frac{.01737/_3}{.002150} = 2.69$	.05
VPX2	.01149	.01149/.002150 = 5.34	.05
VPX1	.00566	.00566/.002150 = 2.63	NS
VPX3	.00022	.00022/.002150 = 0.10	NS

[a] Error Term = (1-.17018)/427-41 = .002150

[b] NS = Nonsignificant

Table 61

Molarity Delayed Posttest (MLT): Calculations for "Fourth" Effect

Verbal X Proportional Reasoning X Treatment Interaction

Effect	B	S.E.B.
VPX2	+.0147	.00699
VPX1	-.0106	.00828
VPX3	+.00268	.00838

$$B_4 = -\Sigma B_i = -(.0147 - .0106 + .00268) = -.00678$$

$$S.E.B._4 = \Sigma \frac{S.E.B._i}{3} = \frac{.00699 + .00828 + .00838}{3} = .00788$$

$$t_4 = \frac{B_4}{S.E.B._4} = \frac{-.00678}{.00788} = -.86 \qquad NS$$

Table 62

Molarity Delayed Posttest (MLT): Verbal Preference (VVQV) X Proportional Reasoning (P) X Treatment (X1-X3) Interactions

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$MLT = -.0557V+.1052P+.00113VP+5.234$
Analogy	$X2 = 1$	$MLT = -.2050V-.1379P+.0168VP+7.742$
Diagram	$X1 = 1$	$MLT = .1350V+.4064P-.0119VP+1.201$
Factor-Label	$X3 = X2 = X1 = -1$	$MLT = .0966V+.2096P-.00581VP+3.418$

Table 63

Molarity Delayed Posttest (MLT):

Substitution of Extreme Values for

VVQV (1 →30) and PPRT (1 →21)

VVQV		PPRT		VP		TREATMENT		PREDICTED MLT
1	-.06	1	.11	1	.00	P	5.234	5.29
30	-1.67	1	.11	30	.03	P	5.234	3.70
1	-.06	21	2.21	21	.02	P	5.234	7.41
30	-1.67	21	2.21	630	.71	P	5.234	6.48
1	-.20	1	-.14	1	.02	A	7.742	7.42
30	-6.15	1	-.14	30	.50	A	7.742	1.96
1	-.20	21	-2.90	21	.35	A	7.742	4.99
30	-6.15	21	-2.90	630	10.58	A	7.742	9.28
1	.14	1	.41	1	-.01	D	1.201	1.73
30	4.05	1	.41	30	-.36	D	1.201	5.30
1	.14	21	8.53	21	-.25	D	1.201	9.62
30	4.05	21	8.53	630	-7.50	D	1.201	6.29
1	.10	1	.21	1	-.01	F	3.418	3.72
30	2.90	1	.21	30	-.17	F	3.418	6.35
1	.10	21	4.40	21	-.12	F	3.418	7.80
30	2.90	21	4.40	630	-3.66	F	3.418	7.06

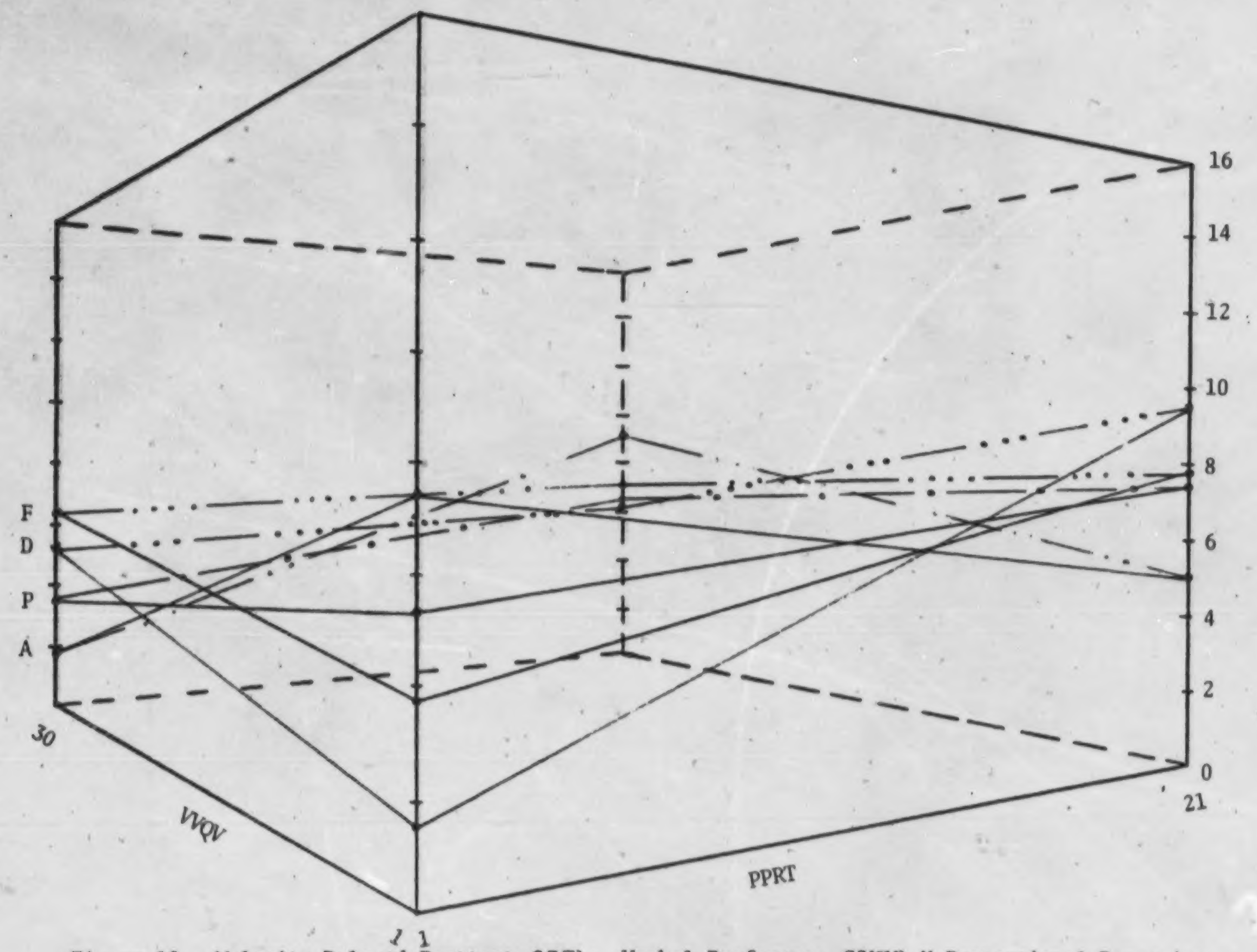

Figure 18. Molarity Delayed Posttest (MLT): Verbal Preference (VVQV) X Proportional Reasoning (P) X Treatment (X1-X3) Interactions

Table 64

Moles Delayed Posttest (MOT):

Verbal Preference (VVQV) X Proportional Reasoning (P) X

Treatment (X1-X3) Interactions

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$MOT = -.0511V+.1038P+.00413VP+5.735$
Analogy	$X2 = 1$	$MOT = .0666V+.2218P-.00329VP+3.916$
Diagram	$X1 = 1$	$MOT = .1330V+.3769P-.0102VP+2.443$
Factor-Label	$X3 = X2 = X1 = -1$	$MOT = -.1279V-.00737P+.00952VP+7.847$

Table 65

Moles Delayed Posttest (MOT): Substitution of Extreme Values for VVQV (1→ 30) and PPRT (1→ 21)

VVQV		PPRT		VP		TREATMENT		PREDICTED MOT
1	-.05	1	.10	1	.00	P	5.735	5.79
30	-1.53	1	.10	30	.12	P	5.735	4.43
1	-.05	21	2.18	21	.09	P	5.735	7.95
30	-1.53	21	2.18	630	2.60	p	5.735	8.98
1	.67	1	.22	1	-.00	A	3.916	4.20
30	2.00	1	.22	30	-.10	A	3.916	6.04
1	.67	21	4.66	21	-.07	A	3.916	8.57
30	2.00	21	4.66	630	-2.07	A	3.916	8.50
1	.13	1	.38	1	-.01	D	2.443	2.94
30	3.99	1	.38	30	-.31	D	2.443	6.50
1	.13	21	7.91	21	-.21	D	2.443	10.28
30	3.99	21	7.91	630	-6.43	D	2.443	7.92
1	-.13	1	-.01	1	.01	F	7.847	7.72
30	-3.84	1	-.01	30	.29	F	7.847	4.29
1	-.13	21	-.15	21	.20	F	7.847	7.76
30	-3.84	21	-.15	630	6.00	F	7.847	9.85

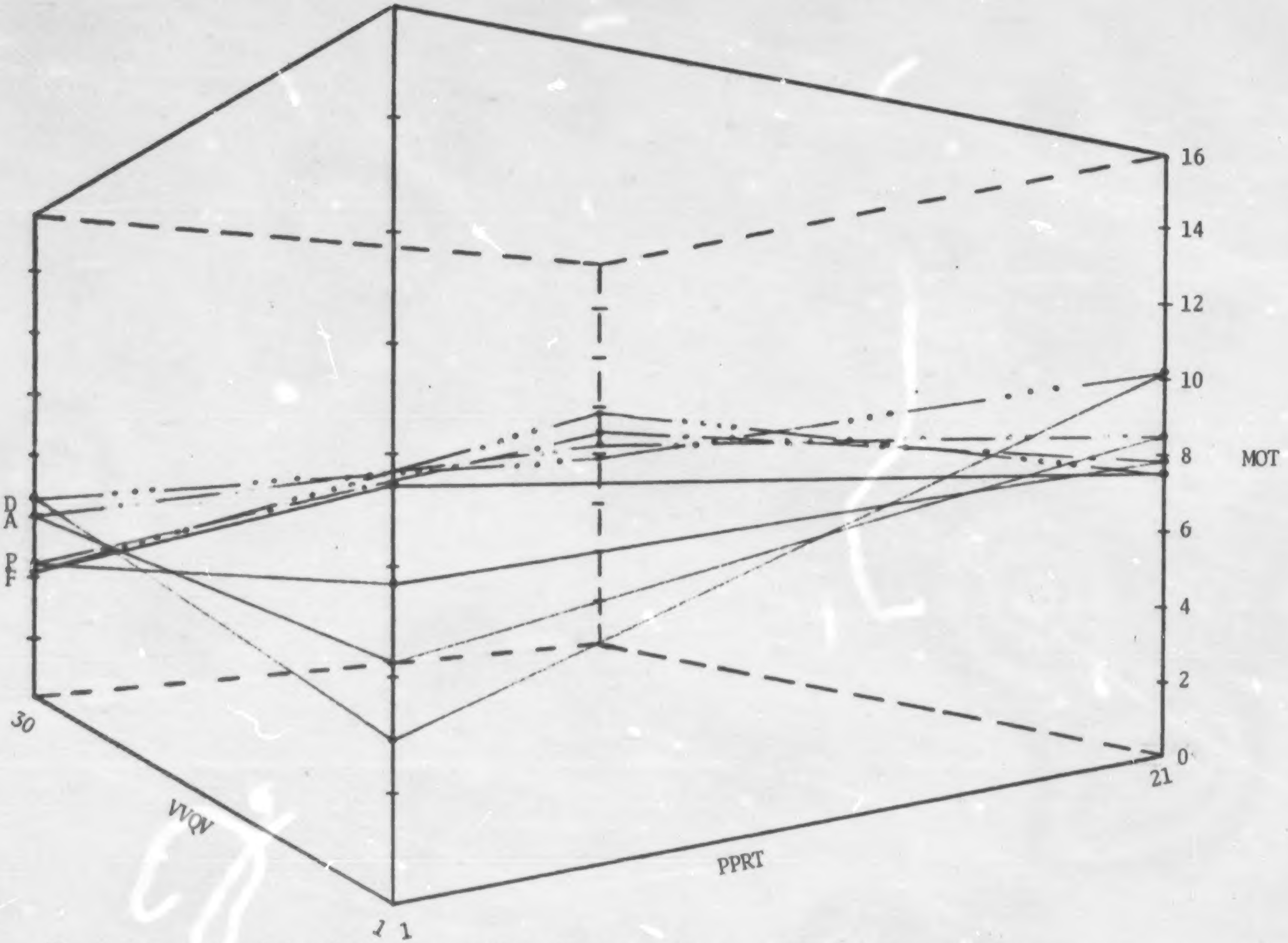

Figure 19. Moles Delayed Posttest (MOT): Verbal Preference (VVQV) X Proportional Reasoning (P) X Treatment (X1-X3) Interactions

Table 66

Gas Laws Delayed Posttest (GLT): Verbal Preference (VVQV) X Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$GLT = .0309V+.0322P-.000770VP+6.624$
Analogy	$X2 = 1$	$GLT = -.0425V+.1081P+.000556VP+5.520$
Diagram	$X1 = 1$	$GLT = -.0336V+.2519P-.00446VP+4.983$
Factor-Label	$X3 = X2 = X1 = -1$	$GLT = -.0810V+.1301P+.00473VP+5.788$

Table 67

Gas Laws Delayed Posttest (GLT):

Substitution of Extreme Values for

VVQV (1 →30) and PPRT (1 →21)

VVQV		PPRT		VP		TREATMENT		PREDICTED GLT
1	.03	1	.03	1	-.00	P	6.624	6.69
30	.93	1	.03	30	-.02	P	6.624	7.56
1	.03	21	.68	21	-.02	P	6.624	7.31
30	.93	21	.68	630	-.49	P	6.624	7.74
1	-.04	1	.11	1	.00	A	5.520	5.59
30	-1.28	1	.11	30	.02	A	5.520	4.37
1	-.04	21	2.27	21	.01	A	5.520	7.76
30	-1.28	21	2.27	630	.35	A	5.520	6.87
1	-.03	1	.25	1	-.00	D	4.983	5.20
30	-1.01	1	.25	30	-.13	D	4.983	4.09
1	-.03	21	5.29	21	-.09	D	4.983	10.15
30	-1.01	21	5.29	630	-2.81	D	4.983	6.46
1	-.08	1	.13	1	.00	F	5.788	5.84
30	-2.43	1	.13	30	.14	F	5.788	3.63
1	-.08	21	2.73	21	.10	F	5.788	8.54
30	-2.43	21	2.73	630	2.98	F	5.788	9.07

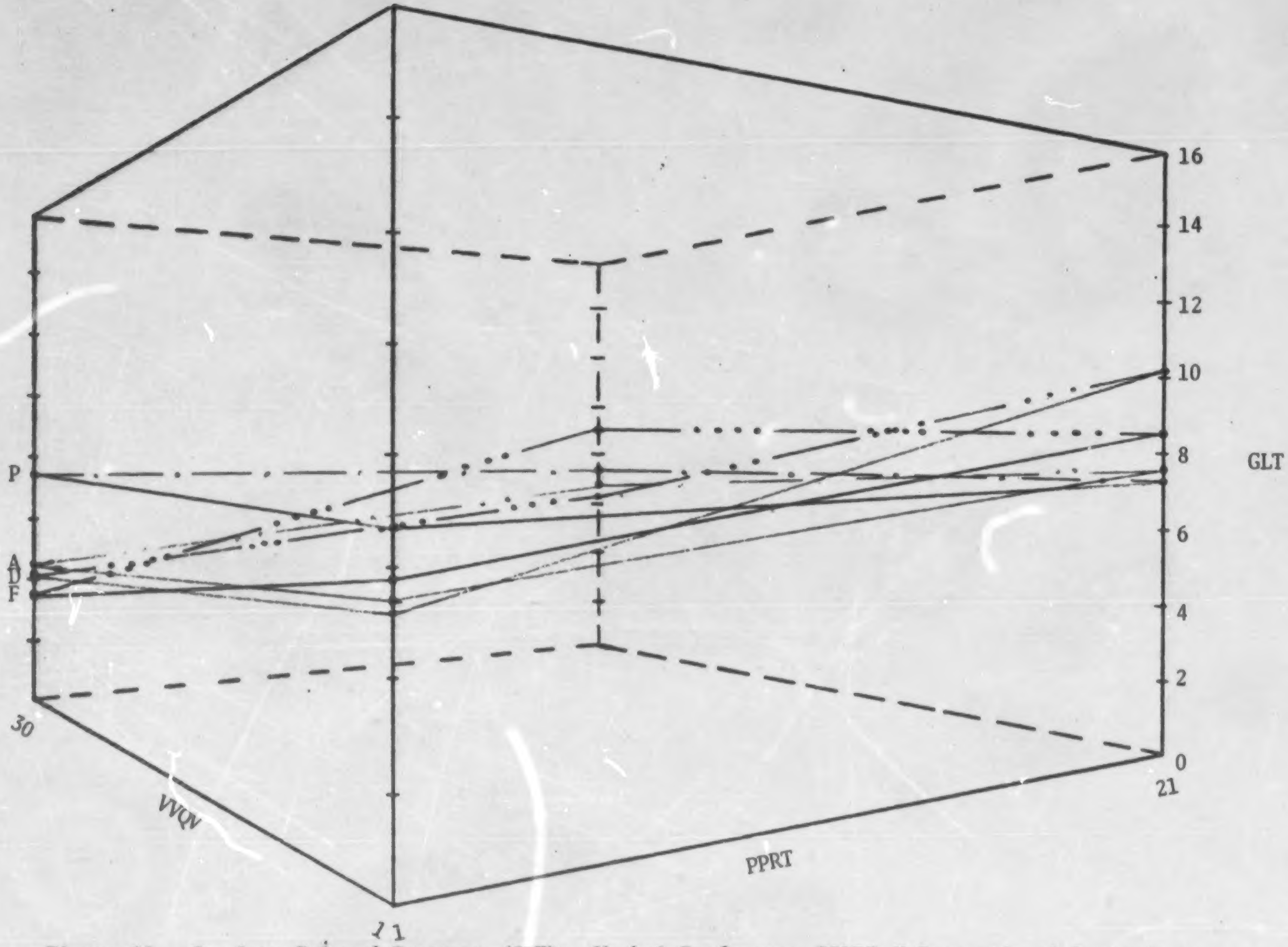

Figure 20. Gas Laws Delayed Posttest (GLT): Verbal Preference (VVQV) X Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Table 68

Stoichiometry Delayed Posttest (ST):

Verbal Preference (VVQV) X Proportional Reasoning (P) X

Treatment (X1-X3) Interactions

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$ST = .1216V+.3184P-.0136VP+3.340$
Analogy	$X2 = 1$	$ST = -.0512V+.1663P+.00325VP+4.964$
Diagram	$X1 = 1$	$ST = -.1471V+.1469P+.00460VP+5.965$
Factor-Label	$X3 = X2 = X1 = -1$	$ST = -.0503V+.0634P+.00561VP+5.656$

Table 69

Stoichiometry Delayed Posttest (ST):

Substitution of Extreme Values for

VVQV (1 → 30) and PPRT (1 → 21)

VVQV		PPRT		VP		TREATMENT		PREDICTED ST
1	.12	1	.32	1	-.01	P	3.340	3.77
30	3.65	1	.32	30	-.41	P	3.340	6.90
1	.12	21	6.69	21	-.29	P	3.340	9.86
30	3.65	21	6.69	630	-8.57	P	3.340	5.11
1	-.05	1	.17	1	.00	A	4.964	5.08
30	-1.54	1	.17	30	.10	A	4.964	3.69
1	-.05	21	3.49	21	.07	A	4.964	8.47
30	-1.54	21	3.49	630	2.05	A	4.964	8.97
1	-.15	1	.15	1	.00	D	5.965	5.97
30	-4.41	1	.15	30	.14	D	5.965	1.84
1	-.15	21	3.08	21	.10	D	5.965	9.00
30	-4.41	21	3.08	630	2.90	D	5.965	7.53
1	-.05	1	.06	1	.01	F	5.656	5.67
30	-1.51	1	.06	30	.17	F	5.656	4.38
1	-.05	21	1.33	21	.12	F	5.656	7.05
30	-1.51	21	1.33	630	3.53	F	5.656	9.01

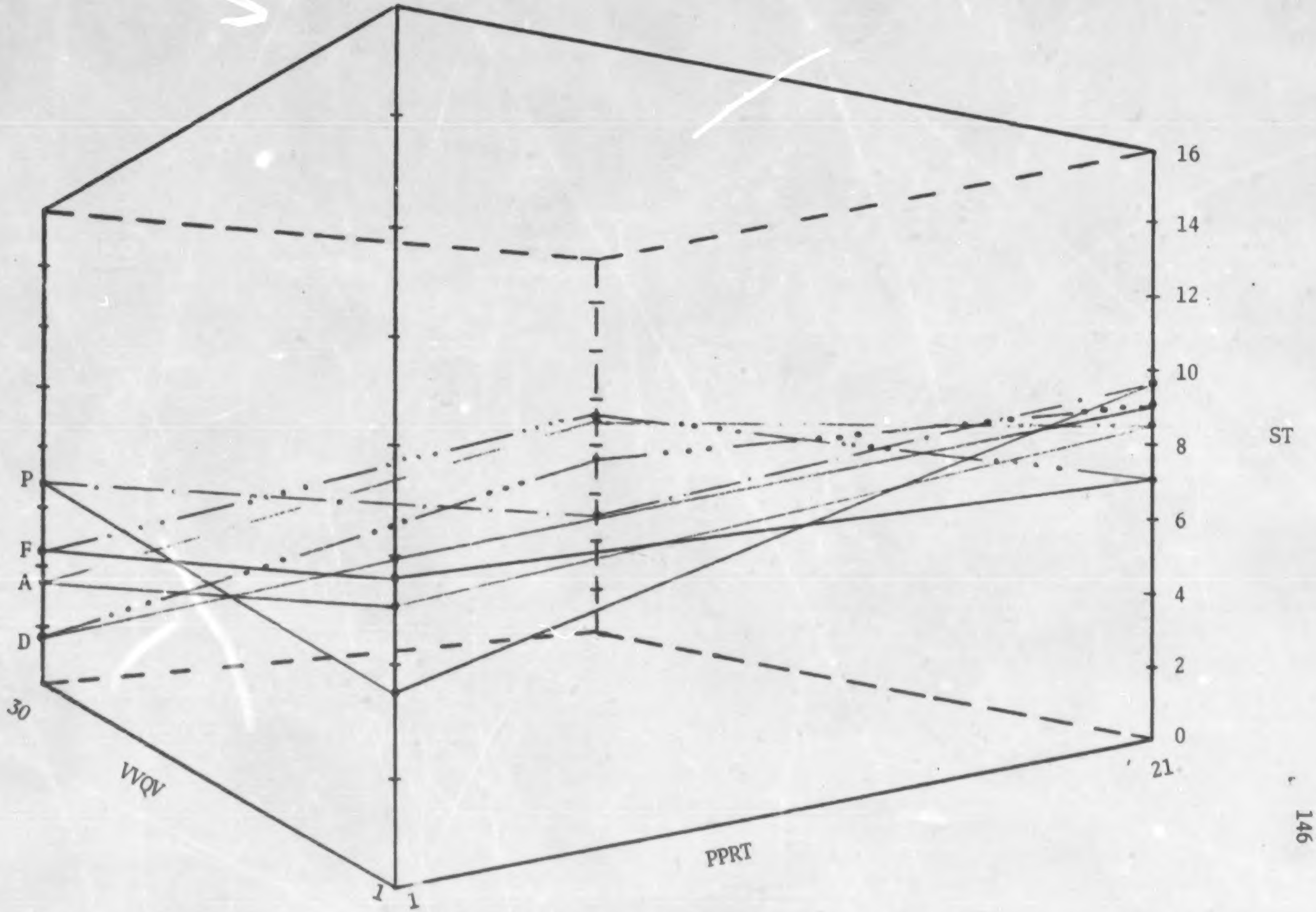

Figure 21. Stoichiometry Delayed Posttest (ST): Verbal Preference (VVQV) X Proportional Reasoning (P) X Treatment (X1-X3) Interactions

174

175

Table 70

Gas Laws Immediate Posttest (GLQT): General Regression Equation

$$\begin{aligned}
\text{GLQT} = {} & -.0249(\text{V}) + .0298(\text{I}) - .00506(\text{MARSTOT}) + .0700(\text{PPRT}) + \\
& 26.729(\text{X3}) - 15.228(\text{X2}) - 38.436(\text{X1}) + .8710(\text{VX2}) + \\
& .9977(\text{VX1}) - 1.108(\text{VX3}) - 1.421(\text{IX3}) + .3831(\text{IX2}) + \\
& 2.067(\text{IX1}) + .2475(\text{MX1}) - .1699(\text{MX3}) - .0582(\text{MX2}) + \\
& 2.427(\text{PX2}) + 1.788(\text{PX1}) - 1.335(\text{PX3}) - .0651(\text{VIX1}) + \\
& .0657(\text{VIX3}) - .0322(\text{VIX2}) - .00970(\text{VMX1}) - .00133(\text{VMX2}) \\
& + .00790(\text{VMX3}) - .0136(\text{IMX1}) + .00922(\text{IMX3}) - .00145 \\
& (\text{IMX2}) - .1378(\text{VPX2}) - .0124(\text{VPX1}) + .0380(\text{VPX3}) - \\
& .1016(\text{IPX1}) + .0755(\text{IPX3}) - .0922(\text{IPX2}) - .0126(\text{PMX1}) \\
& - .0136(\text{PMX2}) + .0108(\text{PMX3}) + .000588(\text{VIMX1}) - .000447 \\
& (\text{VIMX3}) + .0000250(\text{VIMX2}) + .00158(\text{VIPX1}) + .00636(\text{VIPX2}) \\
& - .00268(\text{VIPX3}) + .000412(\text{VPMX1}) + .000644(\text{VPMX2}) - \\
& .000460(\text{VPMX3}) + .000728(\text{IPMX1}) + .000593(\text{IPMX2}) - \\
& .000602(\text{IPMX3}) - .0000277(\text{VIPMX1}) - .0000308(\text{VIPMX2}) \\
& + .0000275(\text{VIPMX3}) + 10.115
\end{aligned}$$

Where $\overline{\text{VVQV}}\ (\bar{\text{V}}) = 15.807$ $\qquad \overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}\ (\bar{\text{I}}) = 18.020$ $\qquad \overline{\text{PPRT}} = 12.614$

Table 71

Gas Laws Immediate Posttest (GLQT): Main Effects Regression Equation

Equation: $GLQT = -.00460\ (MARSTOT) + .0780\ (PPRT) + .767\ (X3) - .379\ (X2) - .356\ (X1) + 10.024$

Where $\overline{MARSTOT} = 184.546$ $\overline{PPRT} = 12.614$

Strategy	Dummy Variables	GLQT
Proportion	$X3 = 1$	10.926^b
Analogy	$X2 = 1$	9.780^a
Diagram	$X1 = 1$	9.803^a
Factor-Label	$X3 = X2 = X1 = -1$	10.127

[a] Significantly lower than mean

[b] Significantly higher than mean

Table 72

Gas Laws Immediate Posttest (GLQT): F Tests for Possible Significant Effects

Mean = 10.188	S.D. = 1.929	Cases = 515	Max. = 12

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.02023	.02023/.001808[a] = 11.19	.01
PPRT	.03016	.03016/.001808 = 16.68	.01
X3 X2 X1	.01914 .02459 .01155 .05528	$\frac{.05528/3}{.001808} = 10.19$	.01
X3	.01914	.01914/.001808 = 10.59	.01
X2	.02459	.02459/.001808 = 13.60	.01
X1	.01155	.01155/.001808 = 6.39	.05
MX1 MX3 MX2	.00955 .00003 .00024 .00982	$\frac{.00982/3}{.001808} = 1.81$	NS[b]
PMX1 PMX2 PMX3	.00466 .00906 .00046 .01418	$\frac{.01418/3}{.001808} = 2.61$	.05
PMX1	.00466	.00466/.001808 = 2.58	NS
PMX2	.00906	.00906/.001808 = 5.01	.05
PMX3	.00046	.00046/.001808 = .25	NS
VIPX1 VIPX2 VIPX3	.00499 .00233 .00200 .00932	$\frac{.00932/3}{.001808} = 1.72$	NS

---

[a] Error Term = (1-.18836)/462-13 = .001808

[b] NS = Nonsignificant

Table 73

Gas Laws Immediate Posttest (GLQT): Calculations for "Fourth" Effect

Factor-Label Treatment

$$t_g = \frac{-g \Sigma B_i}{\sqrt{\tilde{s}d^2_{Y-\hat{Y}} \left[\frac{(g-1)^2}{ng} + \Sigma \frac{1}{n} \right]}} \qquad df = n-k-1$$

$$\tilde{s}d^2_{Y-\hat{Y}} = \tilde{s}d^2_Y (1-R^2) \frac{n}{n-k-1} = 1.929^2 \ (1-.10958) \frac{515-13}{515-7-1-13} = 3.367$$

$$t_4 = \frac{-4(.767- .379 - .356)}{\sqrt{3.367 \left[\frac{(3)^2}{135} + \frac{1}{121} + \frac{1}{136} + \frac{1}{136} \right]}}$$

$$t_4 = \frac{0.128}{\sqrt{3.367 \ (.08964)}} = .23 \qquad NS$$

PPRT X MARSTOT X Treatment Interaction

Effect	B	S.E.B.
PMX1	-.000493	.000666
PMX2	-.00169	.000730
PMX3	+.000426	.000832

$$B_4 = - \Sigma B_i = -(-.000493 - .00169 + .000426) = .00176$$

$$S.E.B._4 = \Sigma \frac{S.E.B._i}{3} = \frac{.000666 + .000730 + .000832}{3} = .000743$$

$$t_4 = \frac{B_4}{S.E.B._4} = \frac{.00176}{.000743} = 2.37 \qquad \text{Sig. } p < .05$$

Table 74

Gas Laws Immediate Posttest (GLQT):

Mathematics Anxiety (M) X Proportional Reasoning Ability (P)

X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$GLQT = -.0115M - .0674P + .00059MP + 12.570$
Analogy	$X2 = 1$	$GLQT = .0132M + .3437P - .00146MP + 6.519$
Diagram	$X1 = 1$	$GLQT = .0108M + .2815P - .00088MP + 6.311$
Factor-Label	$X3 = X2 = X1 = -1$	$GLQT = -.0329M - .2772P + .00175MP + 15.635$

Table 75

Gas Laws Immediate Posttest (GLQT):
Substitution of Extreme Values for
MARSTOT (101 → 349) and PPRT (1 → 21)

MARSTOT		PPRT		MP		TREATMENT		PREDICTED GLQT
101	-1.16	1	-.07	101	.06	P	12.570	11.40
349	-4.01	1	-.07	349	.21	P	12.570	8.70
101	-1.16	21	-1.42	2121	1.25	P	12.570	11.24
349	-4.01	21	-1.42	7329	4.32	P	12.570	11.47
101	1.33	1	.34	101	-.15	A	6.519	8.05
349	4.61	1	.34	349	-.51	A	6.519	10.96
101	1.33	21	7.22	2121	-3.10	A	6.519	11.97
349	4.61	21	7.22	7329	-10.70	A	6.519	7.64
101	1.09	1	.28	101	-.09	D	6.311	7.59
349	3.77	1	.28	349	-.31	D	6.311	10.05
101	1.09	21	5.91	2121	-1.87	D	6.311	11.45
349	3.77	21	5.91	7329	-6.45	D	6.311	9.54
101	-3.32	1	-.28	101	.18	F	15.635	12.21
349	-11.48	1	-.28	349	.61	F	15.635	4.49
101	-3.32	21	-5.82	2121	3.71	F	15.635	10.20
349	-11.48	21	-5.82	7329	12.83	F	15.635	11.16

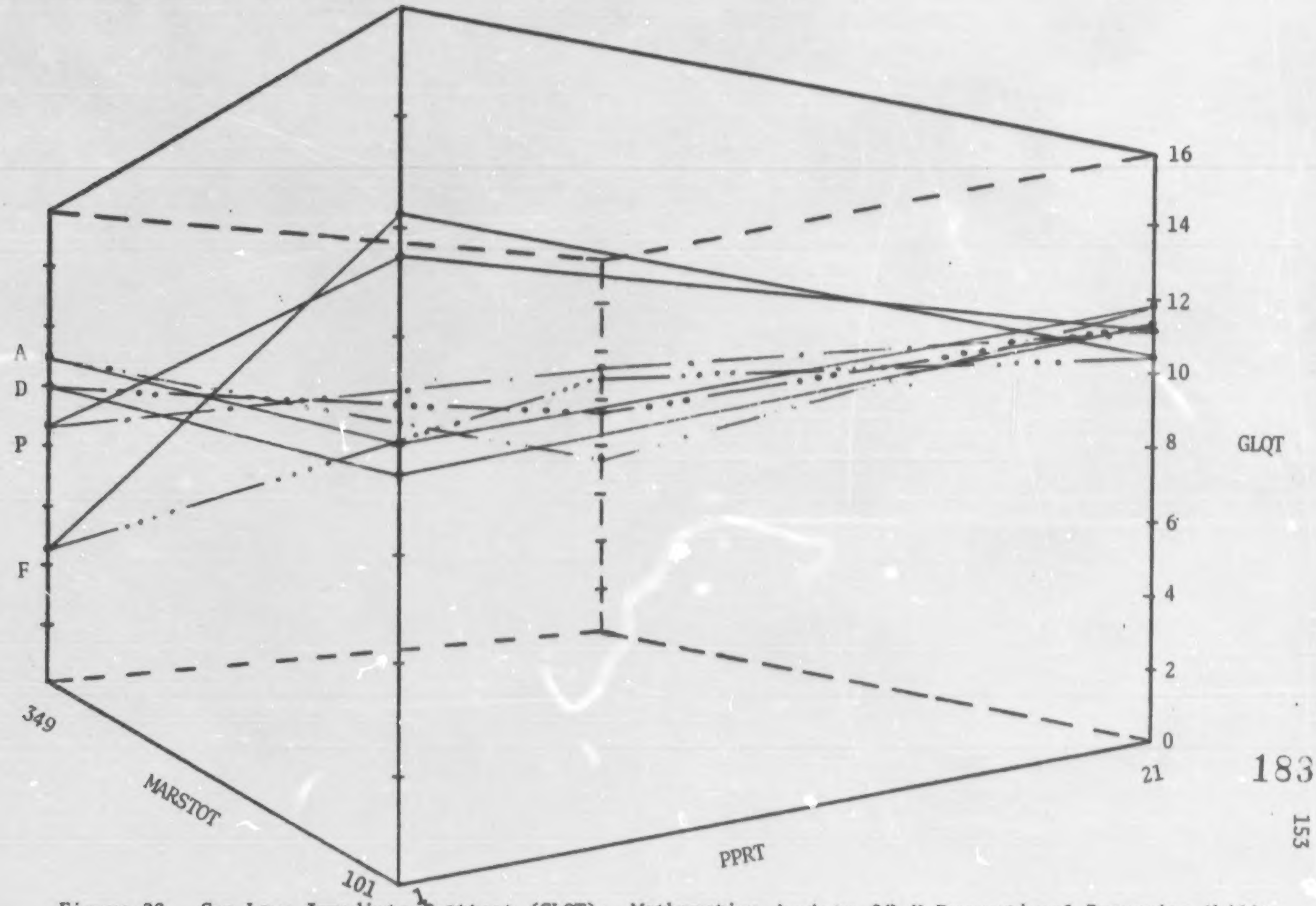

Figure 22. Gas Laws Immediate Posttest (GLQT): Mathematics Anxiety (M) X Proportional Reasoning Ability (P) X Treatment (X1-X3) Interaction

Table 76

Moles Immediate Posttest (MOQT):

Mathematics Anxiety (M) X Proportional Reasoning (P) X

Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$MOQT =+ .0110M + .4551P - .00118MP + 11.124$
Analogy	$X2 = 1$	$MOQT = -.00686M + .1848P + .000303MP + 16.406$
Diagram	$X1 = 1$	$MOQT = .0162M + .5731P - .00211MP + 12.097$
Factor-Label	$X3 = X2 = X1 = -1$	$MOQT = -.0520M - .3473P + .00298MP + 24.298$

Table 77

Moles Immediate Posttest (MOQT):

Substitution of Extreme Values for

MARSTOT (101 → 349) and PPRT (1 → 21)

MARSTOT		PPRT		MP		TREATMENT		PREDICTED MOQT
101	1.11	1	.46	101	-.12	P	11.124	12.57
349	3.84	1	.46	349	-.41	P	11.124	15.01
101	1.11	21	9.56	2121	-2.50	P	11.124	19.29
349	3.84	21	9.56	7329	-8.65	P	11.124	15.87
101	-.69	1	.18	101	.03	A	16.406	15.93
349	- 2.39	1	.18	349	.11	A	16.406	14.30
101	-.69	21	3.88	2121	.64	A	16.406	20.24
349	- 2.39	21	3.88	7329	2.22	A	16.406	20.11
101	1.64	1	.57	101	-.21	D	12.097	14.09
349	5.65	1	.57	349	-.74	D	12.097	17.59
101	1.64	21	12.04	2121	-4.48	D	12.097	21.29
349	5.65	21	12.04	7329	-15.46	D	12.097	14.32
101	-5.25	1	-.35	101	.30	F	24.298	19.00
349	-18.15	1	-.35	349	.04	F	24.298	6.84
101	-5.25	21	-7.29	2121	6.32	F	24.298	18.07
349	-18.15	21	-7.29	7329	21.84	F	24.298	20.70

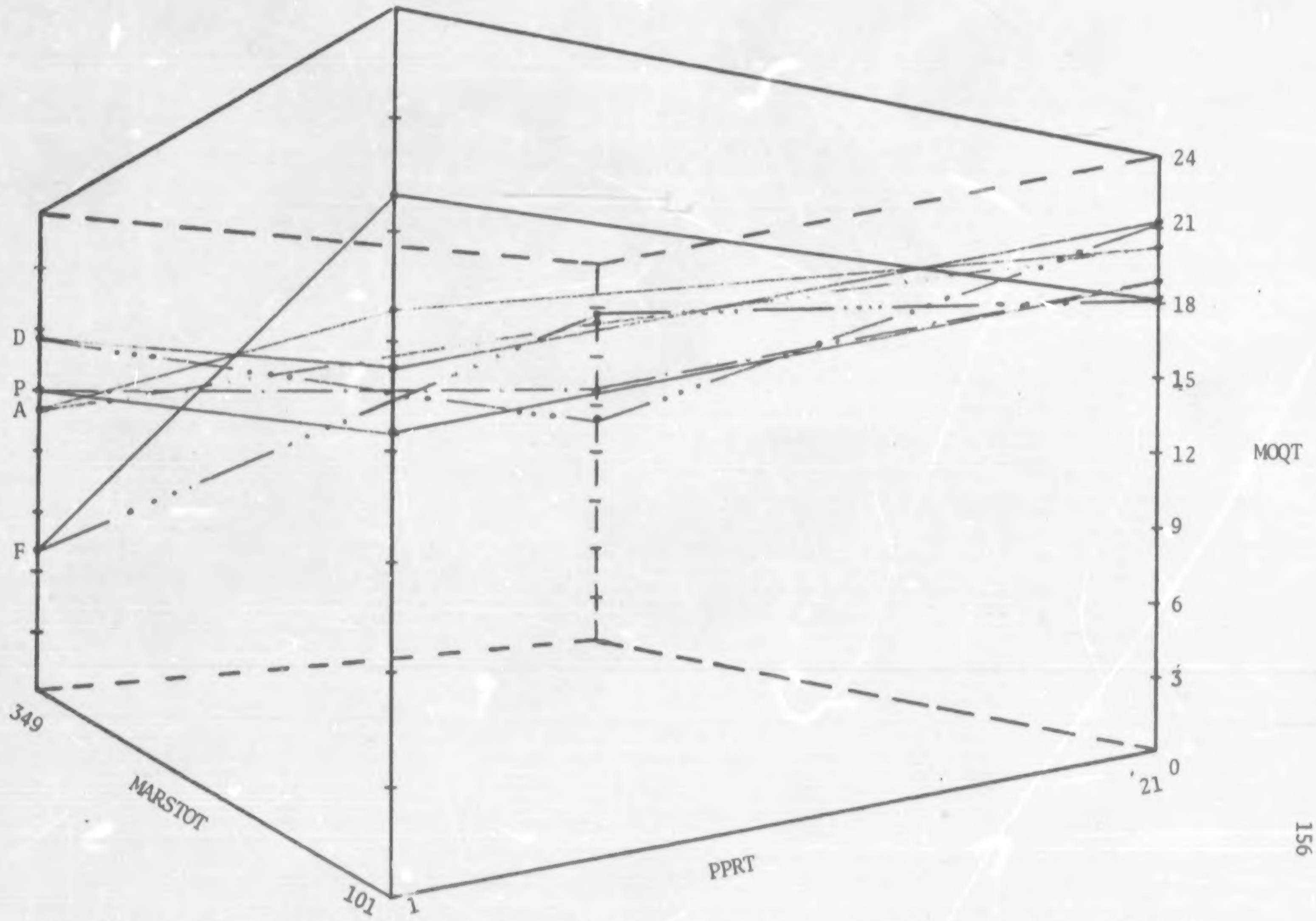

Figure 23. Moles Immediate Posttest (MOQT): Mathematics Anxiety (M) X Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Table 78

Stoichiometry Immediate Posttest (SQT): Mathematics Anxiety (M) X Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$SQT = -.0143M-.0112P+.000790MP+10.159$
Analogy	$X2 = 1$	$SQT = .00371M+.3375P-.00122MP+7.027$
Diagram	$X1 = 1$	$SQT = .0120M+.3896P-.00123MP+5.025$
Factor-Label	$X3 = X2 = X1 = -1$	$SQT = -.0318M-.2028P+.00162MP+14.422$

Table 79

Stoichiometry Immediate Posttest (SQT):

Substitution of Extreme Values for

MARSTOT (101 → 349) and PPRT (1 → 21)

MARSTOT		PPRT		MP		TREATMENT		PREDICTED SQT
101	-1.44	1	-.01	101	.08	P	10.159	8.78
349	-4.99	1	-.01	349	.28	P	10.159	5.43
101	-1.44	21	-.24	2121	1.68	P	10.159	10.51
349	-4.99	21	-.24	7329	5.79	P	10.159	10.72
101	.37	1	.34	101	-.12	A	7.027	7.62
349	1.29	1	.34	349	-.43	A	7.027	8.23
101	.37	21	7.09	2121	-2.59	A	7.027	11.90
349	1.29	21	7.09	7329	-8.94	A	7.027	6.47
101	1.21	1	.39	101	-.12	D	5.025	6.50
349	4.19	1	.39	349	-.43	D	5.025	9.17
101	1.21	21	8.18	2121	-2.61	D	5.025	11.81
349	4.19	21	8.18	7329	-9.01	D	5.025	8.38
101	-3.21	1	-.20	101	.16	F	14.422	11.17
349	-11.10	1	-.20	349	.57	F	14.422	3.69
101	-3.21	21	-4.26	2121	3.44	F	14.422	10.39
349	-11.10	21	-4.26	7329	11.87	F	14.422	10.94

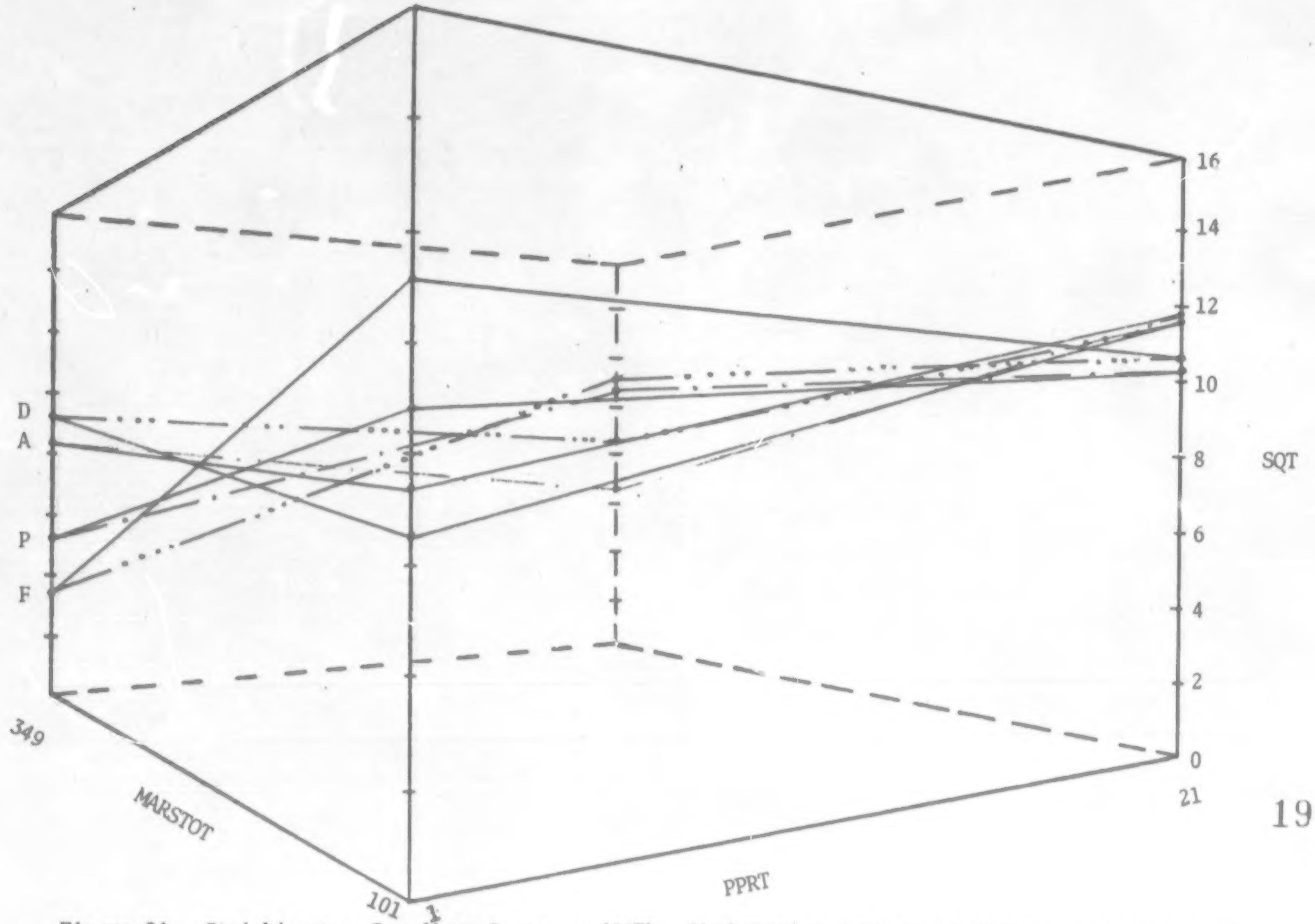

Figure 24. Stoichiometry Immediate Posttest (SQT): Mathematics Anxiety (M) X Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Table 80

Molarity Immediate Posttest (MLQT): Mathematics Anxiety (M) X Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Strategy	Dummy Variables	Equation
Proportion	$X3 = 1$	$MLQT = -.00770M+.0984P+.000220MP+10.456$
Analogy	$X2 = 1$	$MLQT = -.0170M+.0918P+.000526MP+11.975$
Diagram	$X1 = 1$	$MLQT = .00966M+.4068P-.00110MP+7.074$
Factor-Label	$X3 = X2 = X1 = -1$	$MLQT = -.00721M+.0376P+.000435MP+11.515$

Table 81

Molarity Immediate Posttest (MLQT):

Substitution of Extreme Values for

MARSTOT (101→ 349) and PPRT (1 →21)

MARSTOT		PPRT		MP		TREATMENT		PREDICTED MLQT
101	-.78	1	.10	101	.02	P	10.456	9.80
349	-2.69	1	.10	349	.08	P	10.456	7.94
101	-.78	21	2.07	2121	.47	P	10.456	12.21
349	-2.69	21	2.07	7329	1.61	P	10.456	11.45
101	-1.72	1	.09	101	.05	A	11.975	10.40
349	-5.93	1	.09	349	.18	A	11.975	6.32
101	-1.72	21	1.93	2121	1.12	A	11.975	13.30
349	-5.93	21	1.93	7329	3.86	A	11.975	11.82
101	.98	1	.41	101	-.11	D	7.074	8.35
349	3.37	1	.41	349	-.38	D	7.074	10.47
101	.98	21	8.54	2121	-2.33	D	7.074	14.26
349	3.37	21	8.54	7329	-8.06	D	7.074	10.93
101	-.73	1	.04	101	.04	F	11.515	10.87
349	-2.52	1	.04	349	.15	F	11.515	9.19
101	-.73	21	.79	2121	.92	F	11.515	12.50
349	-2.52	21	.79	7329	3.19	F	11.515	12.98

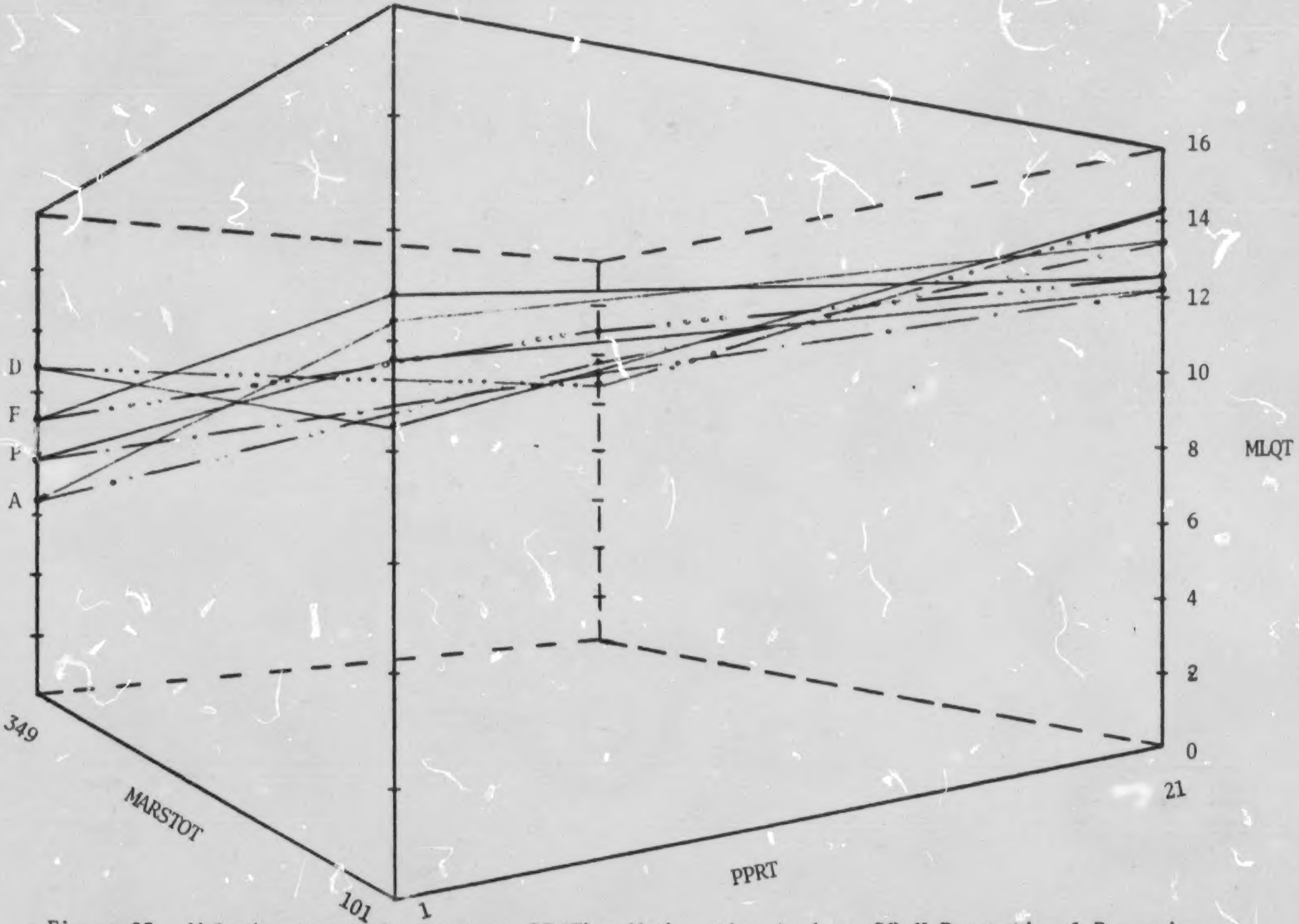

Figure 25. Molarity Immediate Posttest (MLQT): Mathematics Anxiety (M) X Proportional Reasoning (P) X Treatment (X1-X3) Interaction

Table 82

Molarity Immediate Posttest (MLQT): General Regression Equation

MLQT = -.0154(V) + .1122(I) - .00553(MARSTOT) + .1583 (PPRT) +
59.762(X3) + 17.0321(X2) - 64.208(X1) - 2.800(VX2) +
3.621(VX1) - 2.851(VX3) - 3.008(IX3) - .6169(IX2) +
3.293(IX1) + .3453(MX1) - .3930(MX3) - .0440(MX2) -
1.545(PX2) + 4.101(PX1) - 5.923(PX3) - .1950(VIX1) -
.1394(VIX3) + .1407(VIX2) - .0198(VMX1) + .0105(VMX2)
+ .0210(VMX3) - .0192(IMX1) + .0207(IMX3) + .00117
(IMX2) + .2311(VPX2) - .2824(VPX1) + .3654(VPX3) -
.2088(IPX1) + .2916(IPX3) + .0602(IPX2) - .0212
(PMX1) + .00240(PMX2) + .0358(PMX3) + .00115(VIMX1)
- .00111(VIMX3) - .000545(VIMX2) + .0154(VIPX1) -
.0114(VIPX2) - .0181(VIPX3) + .00153(VPMX1) - .000763
(VPMX2) - .00236(VPMX3) - .00121(IPMX1) - .0000512
(IPMX2) - .00184(IPMX3) - .0000911(VIPMX1) + .0000390
(VIPMX2) + .000122(VIPMX3) + 8.477

Where $\overline{VVQV}$ ($\bar{V}$) = 15.807 $\overline{MARSTOT}$ = 184.546

$\overline{VVQI}$ ($\bar{I}$) = 18.020 $\overline{PPRT}$ = 12.614

Table 83

Molarity Immediate Posttest (MLQT): F Tests for Possible Significant Effects

Mean = 11.308 S.D. = 2.907 Cases = 481 Max. = 15

Predictor	ΔR^2	F	Sig.Level
VVQI	.02231	.02231/.002071[a]= 10.80	.01
MARSTOT	.01498	.01498/.002071 = 7.23	.01
PPRT	.06229	.06229/.002071 = 30.08	.01
IMX1	.00225	$\frac{.01267/3}{.002071} = 2.04$	NS[b]
IMX3	.00985		
IMX2	.00057		
	.01267		

---

[a] Error Term = (1-.18415)/427-33 = .002071

[b] NS = Nonsignificant

Table 84

Molarity Immediate Posttest (MLQT): Main Effects Regression Equation

Equation: MLQT = .0964 (VVQI) - .00481 (MARSTOT) + .171 (PPRT)
+ 8.483

Table 85

Moles Delayed Posttest (MOT): General Regression Equation

MOT = +.00524(V) + .0269(I) - .00164 (MARSTOT) + .1735(PPRT)
+ 45.755(X3) + 2.902(X2) - 64.483(X1) + 4.492(VX2) +
2.041(VX1) - 2.193(VX3) - 2.221(IX3) - 1.048(IX2) +
3.994(IX1) + .3392(MX1) - .2872(MX3) - .000665(MX2)
+ 1.141(PX2) + 3.440(PX1) - 2.879 (PX3) - .1448(VIX1)
+ .0978(VIX3) + .0277(VIX2) - .0113(VMX1) - .00212
(VMX2) + .0148(VMX3) - .0218(IMX1) + .0145(IMX3) +
.00452(IMX2) - .1335(VPX2) - .0666(VPX1) + .1443
(VPX3) - .2167(IPX1) + .1395(IPX3) - .00675(IPX2) -
.0177(PMX1) - .00783(PMX2) + .0185(PMX3) + .000835
(VIMX1) - .000708(VIMX3) - .000149(VIMX2) + .0057
(VIPX1) + .00391(VIPX2) - .00637(VIPX3) + .000346
(VPMX1) + .000763(VPMX2) - .000997(VPMX3) - .00118
(IPMX1) - .000143(IPMX2) - .000940(IPMX3) - .0000332
(VIPMX1) - .0000243(VIPMX2) + .0000476(VIMPX3)
+ 4.803

Where $\overline{\text{VVQV}}$ ($\bar{\text{V}}$) = 15.807 $\overline{\text{MARSTOT}}$ = 184.546
$\overline{\text{VVQI}}$ ($\bar{\text{I}}$) = 18.020 $\overline{\text{PPRT}}$ = 12.614

Table 86

Moles Delayed Posttest (MOT): Main Effects Regression Equation

Equation: MOT = -.00207 (MARSTOT) + .168 (PPRT) + 5.313

Table 87

Moles Delayed Posttest (MOT): F Tests for Possible Significant Effects

Mean = 7.289 S.D. = 2.112 Cases = 528 Max. = 10

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.01030	.01030/.001672[a] = 6.16	.05
PPRT	.11247	.11247/.001672 = 67.27	.01
VMX1	.00167	$\frac{.00783/3}{.001672} = 1.56$	NS[b]
VMX2	.00552		
VMX3	.00064		
	.00783		
IMX1	.00655	$\frac{.00907/3}{.001672} = 1.81$	NS
IMX3	.00250		
IMX2	.00002		
	.00907		
VPMX1	.00098	$\frac{.00556/3}{.001672} = 1.11$	NS
VPMX2	.00382		
VPMX3	.00076		
	.00556		
IPMX1	.01011	$\frac{.01273/3}{.001672} = 2.54$	NS
IPMX2	.00173		
IPMX3	.00089		
	.01273		

---

[a] Error Term = (1-.20907)/475-2 = .001672

[b] NS = Nonsignificant

Table 88

Gas Laws Delayed Posttest (GLT): General Regression Equation

$$
\begin{aligned}
\text{GLT} = {} & -.0316(\text{V}) + .0220(\text{I}) - .00481(\text{MARSTOT}) + .1305(\text{PPRT}) \\
& - 34.787(\text{X3}) + .4779(\text{X2}) + 6.915(\text{X1}) - .6679(\text{VX2}) - \\
& .00906(\text{VX1}) + 1.796(\text{VX3}) + 2.699(\text{IX3}) + .00131(\text{IX2}) \\
& - .516(\text{IX1}) - .0353(\text{MX1}) + .1410(\text{MX3}) - .000468(\text{MX2}) \\
& + .1437(\text{PX2}) - .3314(\text{PX1}) + 2.831(\text{PX3}) + .00585(\text{VIX1}) \\
& - .1309(\text{VIX3}) + .0199(\text{VIX2}) - .00270(\text{VMX1}) + .00607 \\
& (\text{VMX2}) - .00585(\text{VMX3}) + .00245(\text{IMX1}) - .0117(\text{IMX3}) \\
& - .000188(\text{IMX2}) + .0673(\text{VPX2}) - .0350(\text{VPX1}) - .1623 \\
& (\text{VPX3}) + .0259(\text{IPX1}) - .2122(\text{IPX3}) - .00927(\text{IPX2}) \\
& + .1631(\text{PMX1}) - .00189(\text{PMX2}) - .0109(\text{PMX3}) + .000120 \\
& (\text{VIMX1}) + .000512(\text{VIMX3}) - .000247(\text{VIMX2}) + .00162 \\
& (\text{VIPX1}) - .00237(\text{VIPX2}) + .0112(\text{VIPX3}) + .000395 \\
& (\text{VPMX1}) - .000536(\text{VPMX2}) + .000575(\text{VPMX3}) - .0000946 \\
& (\text{IPMX1}) + .000105(\text{IPMX2}) + .000875(\text{IPMX3}) - .0000215 \\
& (\text{VIPMX1}) + .0000225(\text{VIPMX2}) - .0000442(\text{VIPMX3}) \\
& + 6.220
\end{aligned}
$$

Where $\overline{\text{VVQV}}$ $(\bar{\text{V}})$ = 15.807 $\overline{\text{MARSTOT}}$ = 184.546

$\overline{\text{VVQI}}$ $(\bar{\text{I}})$ = 18.020 $\overline{\text{PPRT}}$ = 12.614

Table 89

Gas Laws Delayed Posttest (GLT): Main Effects Regression Equation

Equation: $GLT = -.00390\ (MARSTOT) + .153\ (PPRT) + .383\ (X3) - .469\ (X2) - .168\ (X1) + 6.095$

Where $\overline{MARSTOT} = 184.56$ $\overline{PPRT} = 12.614$

Strategy	Dummy Variables	GLT
Proportion	X3 = 1	7.683
Analogy	X2 = 1	6.831[a]
Diagram	X1 = 1	7.132
Factor-Label	X3 = X2 = X1 = -1	7.554

[a] Significantly lower than mean

Table 90

Gas Laws Delayed Posttest (GLT): F Tests for Possible Significant Effects

Mean = 6.942 S.D. = 2.523 Cases = 515 Max. = 16

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.01314	.01314/.001806[a]= 7.27	.01
PPRT	.06643	.06643/.001806 = 36.78	.01
X3 X2 X1	.00019 .01621 .00151 .01791	$\frac{.01791/3}{.001806} = 3.31$	.05
X3	.00019	.00019/.001806 = .11	NS[b]
X2	.01621	.01621/.001806 = 8.98	.01
X1	.00151	.00151/.001806 = .84	NS
PX2 PX1 PX3	.00000 .00040 .00783 .00822	$\frac{.00822/3}{.001806} = 1.52$	NS

---

[a] Error Term = (1-.16555)/463 = 0.001806

[b] NS = Nonsignificant

Table 91

Gas Laws Delayed Posttest (GLT): Calculations for "Fourth" Effect

Factor-Label Treatment

$$t_g = \frac{-g \Sigma B_i}{\sqrt{\tilde{s}d^2_{Y-\hat{Y}} \left[\frac{(g-1)^2}{ng} + \Sigma \frac{1}{n_i}\right]}} \qquad df = n-k-1$$

$$\tilde{s}d^2_{Y-\hat{Y}} = \tilde{s}d^2_{Y}(1-R)^2 \frac{n}{n-k-1} = 2.523^2 (1-.10140) \frac{515}{515-7-1} = 5.81$$

$$t_4 = \frac{-4(.383 - .469 - .168)}{\sqrt{5.81 \left[\frac{(3)^2}{135} + \frac{1}{121} + \frac{1}{136} + \frac{1}{136}\right]}}$$

$$t_4 = \frac{1.016}{\sqrt{5.81(.08964)}} = 1.41 \qquad \text{NS}$$

Table 92

Stoichiometry Delayed Posttest (ST): General Regression Equation

$$\begin{aligned}
\text{ST} = {} & -.0317(\text{V}) - .0193(\text{I}) - .00899(\text{MARSTOT}) + .1737(\text{PPRT}) \\
& - 9.168(\text{X3}) + 1.300(\text{X2}) - 5.708(\text{X1}) - 1.801(\text{VX2}) + \\
& .423(\text{VX1}) + 1.046(\text{VX3}) + .3059(\text{IX3}) + .0381(\text{IX2}) + \\
& .682(\text{IX1}) + .0633(\text{MX1}) - .0343(\text{MX3}) + .0163(\text{MX2}) + \\
& .9360(\text{PX2}) - .2066(\text{PX1}) + 1.741(\text{PX3}) - .0435(\text{VIX1}) \\
& - .0533(\text{VIX3}) - .0909(\text{VIX2}) - .00617(\text{VMX1}) + .00892 \\
& (\text{VMX2}) - .000308(\text{VMX3}) - .00519(\text{IMX1}) + .00251(\text{IMX3}) \\
& - .00151(\text{IMX2}) + .0746(\text{VPX2}) + .00135(\text{VPX1}) - .148 \\
& (\text{VPX3}) - .0134(\text{IPX1}) - .0900(\text{IPX3}) - .0458(\text{IPX2}) - \\
& .00128(\text{PMX1}) - .00685(\text{PMX2}) - .00135(\text{PMX3}) + .000416 \\
& (\text{VIMX1}) - .0000377(\text{VIMX3}) - .000452(\text{VIMX2}) + .00117 \\
& (\text{VIPX1}) - .00395(\text{VIPX2}) + .00827(\text{VIPX3}) + .000258(\text{VPMX1}) \\
& - .000334(\text{VPMX2}) + .000295(\text{VPMX3}) + .000198(\text{IPMX1}) + \\
& .000344(\text{IPMX2}) + .0000824(\text{IPMX3}) - .0000197(\text{VIPMX1}) + \\
& .0000184(\text{VIPMX2}) - .0000207(\text{VIPMX3}) + 6.989
\end{aligned}$$

Where $\overline{\text{VVQV}}$ $(\overline{\text{V}}) = 15.807$ $\quad$ $\overline{\text{MARSTOT}} = 184.546$

$\overline{\text{VVQI}}$ $(\overline{\text{I}}) = 18.020$ $\quad$ $\overline{\text{PPRT}} = 12.614$

Table 93

Stoichiometry Delayed Posttest (ST): Main Effects Regression Equation

Equation: $ST = .00798\ (MARSTOT) + .188\ (PPRT) + 6.927$

Table 94

Stoichiometry Delayed Posttest (ST): F Tests for Possible Significant Effects

Mean = 6.719 S.D. = 2.757 Cases = 528 Max. = 10

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.03557	.03557/.001774[a] = 20.05	.01
PPRT	.08180	.08180/.001774 = 46.11	.01
VX2	.00000	$\frac{.00603/3}{.001774} = 1.13$	NS[b]
VX1	.00602		
VX3	.00001		
	.00603		

[a] Error Term = (1-.17158)/475-8 = .001774

[b] NS = Nonsignificant

Table 95

ACS-NSTA Problems Subtest (ACSPROB): General Regression Equation

---

ACSPROB = + .00918(V) + .0293(I) - .00436(MARSTOT) + .1966(PPRT)
- 29.4124(X2) - 57.196(X1) + 129.818(X3) + 2.329(VX2)
+ 1.151(VX1) - 7.938(VX3) + 3.363(IX1) + 1.093(IX2)
- 6.139(IX3) + .3843(MX1) - .7575(MX3) +.1870(MX2)
+ 3.880(PX2) + 2.655(PX1) - 9.024(PX3) - .0862(VIX1)
- .0947(VIX2) + .3895(VIX3) - .0129(VMX1) - .0143(VMX2)
+ .4749(VMX3) - .0234(IMX1) - .00749(IMX2) + .0369(IMX3)
- .2809(VPX2) - .00385(VPX1) + .5565(VPX3) - .1716(IPX1)
- .1652(IPX2) + .4365(IPX3) - .0197(PMX1) - .0212(PMX2)
+ .0513(PMX3) + .000918(VIMX1) + .000594(VIMX2) - .00242
(VIMX3) + .00274(VIPX1) + .0123(VIPX2) - .0281(VIPX3)
- .00156(VPMX2) + .000487(VPMX1) - .00329(VPMX3) +
.000915(IPMX2) + .00130(IPMX1) - .00257(IPMX3) -
.0000469(VIPMX1) - .0000686(VIPMX2) + .000174(VIPMX3)
+ 2.495

Where $\overline{\text{VVQV}}$ $(\overline{\text{V}})$ 15.807 $\overline{\text{MARSTOT}}$ = 184.546

$\overline{\text{VVQI}}$ $(\overline{\text{I}})$ 18.020 $\overline{\text{PPRT}}$ = 12.614

Table 96

ACS-NSTA Problem Subtest (ACSPROB): Main Effects Regression Equation

Equation: $\text{ACSPROB} = -.00368\ (\text{MARSTOT}) + .194\ (\text{PPRT}) + 3.298$

Table 97

ACS-NSTA Problems Subtest (ACSPROB): F Tests for Possible Significant Effects

Mean = 4.944 S.D. = 2.245 Cases = 377 Max. = 10

Predictor	ΔR^2	F	Sig.Level
MARSTOT	.02154	$.02154/.002222^{a} = 9.69$	.01
PPRT	.13670	$.13670/.002222 = 61.52$	.01
PMX1	.00005	$\frac{.01462/_3}{.002222} = 2.19$	NS[b]
PMX2	.00054		
PMX3	.01403		
	.01462		
VIPX1	.01237	$\frac{.01350/_3}{.002222} = 2.03$	NS
VIPX2	.00083		
VIPX3	.00030		
	.01350		
VIPMX1	.00026	$\frac{.01213/_3}{.002222} = 1.82$	NS
VIPMX2	.00005		
VIPMX3	.01182		
	.01213		
VPMX2	.00113	$\frac{.00699/_3}{.002222} = 1.05$	NS
VPMX1	.00548		
VPMX3	.00038		
	.00699		

[a] Error Term = (1-.28004)/324 = .002222

[b] NS = Nonsignificant

Table 98

ACS-NSTA Nonproblems Subtest (ACSNPROB):

General Regression Equation

$$\begin{aligned}
\mathrm{ACSNPROB} = {} & +.00693(\mathrm{V}) + .0524(\mathrm{I}) - .00731(\mathrm{MARSTOT}) + .3937(\mathrm{PPRT}) \\
& - 3.4779(\mathrm{X2}) - 71.362(\mathrm{X1}) + 160.455(\mathrm{X3}) + 1.812(\mathrm{VX2}) \\
& + 2.667(\mathrm{VX1}) - 8.499(\mathrm{VX3}) + 3.864(\mathrm{IX1}) - 1.159(\mathrm{IX2}) \\
& - 6.968(\mathrm{IX3}) + .5057(\mathrm{MX1}) - .9678(\mathrm{MX3}) + .0369(\mathrm{MX2}) \\
& + 1.884(\mathrm{PX2}) + 2.679(\mathrm{PX1}) - 9.341(\mathrm{PX3}) - .1803(\mathrm{VIX1}) \\
& - .0110(\mathrm{VIX2}) + .3824(\mathrm{VIX3}) - .0220(\mathrm{VMX1}) - .00858 \\
& (\mathrm{VMX2}) + .0519(\mathrm{VMX3}) - .0300(\mathrm{IMX1}) + .00396(\mathrm{IMX2}) \\
& + .0450(\mathrm{IMX3}) - .2286(\mathrm{VPX2}) - .0232(\mathrm{VPX1}) + .4012 \\
& (\mathrm{VPX3}) - .1442(\mathrm{IPX1}) - .0214(\mathrm{IPX2}) + .3919(\mathrm{IPX3}) \\
& - .0228(\mathrm{PMX1}) - .00892(\mathrm{PMX2}) + .0547(\mathrm{PMX3}) + .00156 \\
& (\mathrm{VIMX1}) + .0000553(\mathrm{VIMX2}) - .00252(\mathrm{VIMX3}) + .00422 \\
& (\mathrm{VIPX1}) + .00685(\mathrm{VIPX2}) - .0173(\mathrm{VIPX3}) + .00113(\mathrm{VPMX2}) \\
& + .006660(\mathrm{VPMX1}) - .00254(\mathrm{VPMX3}) + .000109(\mathrm{IPMX2}) \\
& + .00143(\mathrm{IPMX1}) - .00247(\mathrm{IPMX3}) - .0000652(\mathrm{VIPMX1}) \\
& - .0000341(\mathrm{VIPMX2}) + .000123(\mathrm{VIPMX3}) + 8.468
\end{aligned}$$

Where $\overline{\mathrm{VVQV}}\ (\overline{\mathrm{V}}) = 15.807$ $\qquad \overline{\mathrm{MARSTOT}} = 184.546$

$\overline{\mathrm{VVQI}}\ (\overline{\mathrm{I}}) = 18.020$ $\qquad \overline{\mathrm{PPRT}} = 12.614$

Table 99

ACS-NSTA Nonproblems Subtest (ACSNPROB): Main Effects Regression Equation

Equation: $ACSNPROB = -.00706\ (MARSTOT) + .398\ (PPRT) + 10.250$

Table 100

ACS-NSTA Nonproblems Subtest (ACSNPROB): F Tests for Possible Significant Effects

Mean = 13.454	S.D. = 4.243	Cases = 377	Max. = 30

Predictor	ΔR^2	F	Sig. Level
MARSTOT	.02361	.02361/.002205[a] = 10.71	.01
PPRT	.16093	.16093/.002205 = 72.98	.01
IX1 IX2 IX3	.00040 .01091 .00401 .01532	$\frac{.01532/3}{.002205} = 2.32$	NS[b]
PMX1 PMX2 PMX3	.00103 .00340 .01033 .01476	$\frac{.01476/3}{.002205} = 2.23$	NS

[a] Error Term = (1-.28569)/324 = .002205

[b] NS = Nonsignificant

Table 101

Results of the

Decimal-Nondecimal Subtests Comparison

Test	n	$\bar{x}$	S.D.	S.E.	t	p
Decimal	421	10.81	1.90	.093	6.49	<.001
Nondecimal	421	11.31	1.48	.072		

Table 102

Means on ACS-NSTA Exam

According to Notation Used

Notation	n	$\overline{x}$	Scheffe p
None	315	16.62	-
Some	28	17.79	-
Complete	166	20.63	.05

Table 103

Analysis of Variance for Amount of Notation Used

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob
Between Groups	2	1744	872	32.95	<.0001
Within Groups	506	13394	26		
Total	508	15138			

Table 104

Chi Square Analysis of Differences of Notation According to Strategy

	Degree of Notation		
Treatment	None	Some	Complete
Factor-Label	71[a]	4	56
	54.2[b]	3.1	42.7
	22.5[c]	14.3	33.7
	13.9[d]	.8	11.0
	80	8	43
	61.1	6.1	32.8
Analogy	25.4	28.6	25.9
	15.7	1.6	8.4
	82	10	38
	63.1	7.7	29.2
Diagram	26.0	35.7	22.9
	16.1	2.0	7.5
	82	6	29
	70.1	5.1	24.8
Proportion	26.0	21.4	17.5
	16.1	1.2	5.7
	315	28	166
	61.9	5.5	32.6

Chi Square	12.03
df	6
V	.11
Significance	.06

---

[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage

Table 105

Means for Total Time Analysis of Data for Proportional Reasoning Ability

Treatments	Proportional Reasoning Ability Low	 High	 Row Total
Non-Proportional	63	60	61
	16	24	40
	1004	1437	2441
	15	17	16
Proportional	59	75	67
	6	6	12
	355	450	805
	12	19	17
Column Total	62[a]	63	62
	22[b]	30	52
	1359[c]	1187	3246
	14[d]	19	17

[a] Mean
[b] Count
[c] Sum
[d] Standard Deviation

Table 106

Analysis of Variance for

Proportional Reasoning Total -

Time Analysis for Gas Laws

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	370	2	185	.69	.51
Treatment	354	1	354	1.31	.26
PPRT	31	1	31	.116	.73
2-Way Interaction	800	1	800	2.96	.09
Explained	1170	3	390	1.44	.24
Residual	12960	48	270		
Total	14131	51	277		

Table 107

Means for Total Time Analysis of Molarity Data for Proportional Reasoning Ability

	Proportional Reasoning Ability		
Treatments	Low	High	Row Total
Non-Proportional	129	110	117
	12	23	35
	1547	2538	4085
	37	34	35
Proportional	143	118	127
	3	5	8
	430	589	1019
	36	21	28
Column Total	132[a]	112	118
	15[b]	28	43
	1977[c]	3127	5104
	35[d]	32	34

[a] Mean
[b] Count
[c] Sum
[d] Standard Deviation

Table 108

Analysis of Variance for

Proportional Reasoning Total -

Time Analysis for Molarity

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	4607	2	2304	2.05	.14
Treatment	653	1	653	.58	.45
PPRT	3868	1	3868	3.43	.07
2-Way Interaction	73	1	73	.06	.80
Explained	4681	3	1560	1.38	.26
Residual	43927	39	1126		
Total	48609	42	1157		

Table 109

Summary of Questionnaire Data

		Number				Percentage			
Item	Response	F	A	D	P	F	A	D	P
1	Never Skipped	55	46	27	52	45	37	23	45
	Skipped part or all	65	71	88	55	53	57	75	48
	Response not clear	3	7	2	8	2	6	2	7
2	If skipped, more toward end	28	18	32	23	23	15	27	20
	More toward start	4	4	6	4	3	3	5	3
	Response not clear	9	4	10	7	7	3	9	6
	No response	10	26	19	9	8	21	16	8
	All four units	16	21	21	16	13	17	18	14
	Didn't skip	56	51	29	56	46	41	25	49
3	Yes	110	75	67	92	89	60	57	80
	Undecided	0	3	0	1	0	2	0	1
	No	13	32	35	20	11	26	30	17
	No response	0	14	15	2	0	11	13	2
4	All of the time (yes)	106	56	42	101	86	45	36	88
	Part of the time	12	24	26	11	10	19	22	10
	Undecided	0	1	0	0	0	1	0	0
	Never (no)	4	36	45	3	3	29	38	3
	No response	1	7	4	0	1	6	3	0
5	Teacher	11	9	4	5	9	7	3	4
	Another student	1	1	1	3	1	1	1	3
	Textbook	2	1	2	0	2	1	2	0
	Different packet	5	2	0	2	4	2	0	2
	No response	98	89	74	94	80	72	63	82
	Other	6	22	36	11	5	18	31	10
6	None or blank	104	112	105	79	85	90	90	69
	Left out details	10	7	5	30	8	6	4	26
	Other	9	5	7	6	7	4	6	5
7	Yes	11	11	6	7	9	9	5	6
	No	107	108	105	103	87	87	90	90
	Sometimes	2	1	1	1	2	1	1	1
	No response	3	4	5	4	2	3	4	3
		123	124	117	115	100	100	100	100

Table 110

Responses to Questionnaire No. 8

Response	Number				
	Factor-Label	Analogy	Diagram	Proportion	Total
Very explanatory	26	18	9	5	58
Answers given	12	7	11	11	41
Easy and fast	6	14	9	7	36
Helped	15	7	3	8	33
Self pacing/help	4	7	3	8	22
Examples	9	7	6	0	22
Step-by-step (logical)	7	1	3	6	17
Better than class (teacher)	2	5	7	2	16
Better than book	2	3	3	5	13
Practice problems	0	3	4	3	10

Table 111

Responses to Questionnaire No. 9

	Number				
Response	Factor-Label	Analogy	Diagram	Proportion	Total
Too long or too many	22	14	13	23	72
Boring (monotonous)	7	8	12	9	36
Method itself	0	20	6	0	26
Confusing, complicated	6	5	6	7	24
Tests or quizzes	5	7	2	4	24
Not enough time	3	7	5	5	20
Moved too fast	5	3	2	6	16
Problems/math	3	2	4	4	13
Repetitious	2	4	0	4	10
Not enough practice, review or explanation	2	2	1	2	7
Keeping packets	0	3	2	0	5
Too hard	1	1	2	1	5
Too easy	2	0	0	3	5

INTERVIEW STUDY

The second part of this investigation consisted of an interview study to determine the processes that students use in solving chemistry problems. This also provided a follow-up on the aptitude by treatment interaction study to see if students were using the teaching strategies (treatments) taught.

Background Information

The use of an interview technique to determine students' problem solving behavior has certain advantages over paper and pencil techniques. Much more information can be gathered in an unobtrusive manner about what students are actually thinking through the use of interviews. On the other hand, there are always the disadvantages of using a small sample size (interviewing students and analyzing the interviews is a time-consuming process) of possible inconsistency across interviews and among interviewers, and possible lack of reliability in the coding of the interviews.

The approach used in this study was one of having students think aloud while solving the problems. In mathematics this approach which follows that used by Kilpatrick (1967) is fairly common. Kilpatrick tape-recorded students' solving problems out loud and then in order to trace the solution path, developed a coding scheme based on Polya's heuristics. This included examining whether students understood the problem, devised a plan for solving it, carried out the plan, and evaluated what had been done. Subsequent studies in mathematics have modified Kilpatricks' system by adding more specific process behavior (for example, Lucas, 1974; Kantowski, 1974; and, Days, 1977). At the present time, Kulm of Purdue University is synthesizing data of interviews made by 17 other investigators using a modification of a protocol developed by Smith (1977) which is somewhat content free.

Using an interview technique to determine students' problem solving processes in science is not new. In the area of physics, work has been done by Towbridge and McDermott (1980) at the University of Washington and Clement (1979) at the University of Massachusetts. The techniques used by both investigators involved more intervention than that used in the "think aloud" technique.

In the area of chemistry, Nurrenbern, (1979) studied high school students' behavior when solving stoichiometric limiting - reagent problems. She compared the processes used by formal and concrete students using the "think aloud" technique, and coded data according to a schema based on that of Days (1977). Because of the similarity of this project to her dissertation study and in order to compare these results with hers and those available in mathematics education, the "think aloud" technique was used for this study. Data were coded using a modification of the Nurrenbern coding sheet.

Questions Studied

This interview study sought to answer the following questions:

1. Are there differences in the problem solving strategies used by students of different verbal-visual preference?

2. Are there differences in the problem solving strategies used by students of different proportional reasoning ability?

3. Are there differences in the problem solving strategies used by students who are successful problem solvers versus those classified as unsuccessful?

4. Are there differences in the problem solving strategies used by students who have been taught to solve problems according to different methods?

5. Are there differences in the problem solving strategies of students who solve the problem correctly versus those who do not?

6. Are the number of questions a student answers correctly related to their verbal-visual preference, their proportional reasoning ability, whether

they are successful/unsuccessful in problem solving, the method used in learning to solve problems and the number of problems solved correctly?

Methods and Procedures

Sample

The major objective of this study was to compare processes students used who were successful problem solvers with those who were unsuccessful. Some criterion had to be selected on which success could be judged. There were two possible options. Success could be judged by outcomes on the problems students were asked to solve while being interviewed. The other alternative was to judge success on the basis of how well students performed on the immediate or delayed posttests administered for the aptitude by treatment interaction study. Because the success rate was so low on the problems students solved while thinking aloud, and because it was impossible to know this in advance of the interviews, the decision was made to base success or lack thereof on students' scores on the immediate and delayed posttests.

If this interview study had not followed the treatments in Part I of this study, there would have been no need to be concerned about other classifications for selection of students to be interviewed. Because this was not the case, an effort was made to select students for interviews who had various degrees of proportional reasoning ability and verbal-visual preferences. The ideal selection process would have been to include students in each of the categories shown in Figure 26 . It was originally intended that eight successful and eight unsuccessful students in each cell for each of the four chemistry topics studied (moles, gas laws, stoichiometry, and molarity) be included in the study. This would have resulted in 64 students per topic or a total of 256 interviews.

In reality it was not feasible to obtain this distribution for several reasons. First, for some of the categories the number of students having the

Ideal Sample

Proportional Reasoning

	Low		High	
	S	U	S	U
Visual	8	8	8	8
Verbal	8	8	8	8

Actual Samples

Moles Unit

Proportional Reasoning

	Low		High	
	S	U	S	U
Visual	5	11	15	5
Verbal	6	14	12	3

Gas Laws Unit

Proportional Reasoning

	Low		High	
	S	U	S	U
Visual	2	12	8	8
Verbal	9	10	9	6

Stoichiometry Unit

Proportional Reasoning

	Low		High	
	S	U	S	U
Visual	8	7	11	7
Verbal	3	13	12	5

Molarity Unit

Proportional Reasoning

	Low		High	
	S	U	S	U
Visual	5	8	10	7
Verbal	10	5	7	3

Figure 26 . Ideal sample versus real samples of students interviewed.

desired characteristics was expected to be small. For example, most students who had high proportional reasoning ability were successful and those with low proportional reasoning ability unsuccessful. Second, an attempt was made not to interview any students a second time. (This happened in no more than 2% of the interviews.) These reasons, together with the fact that there were a limited number of students from whom to select, (had taken the original aptitude tests, obtained permission from their parents and wanted to participate) made it difficult to find students with the correct combination of aptitudes who were available during the times when interviews were conducted.

As the interviews progressed, another factor became evident. Some students who did very poorly on the tests were poor candidates for interviews because their reason for doing poorly was that they were absent from school frequently and had not had the appropriate instruction. An effort was made to avoid interviewing these types of students as the project progressed.

Because of the above considerations, the resulting number of students in each category was not equal. The actual distribution based on the delayed posttest scores is shown in Figure 26 .

Procedures

The following procedures were used for the interview study:

1. After students had completed both the immediate and delayed posttests for each unit, results were obtained and selection of students made on the basis of their aptitude scores on the proportional reasoning test, the verbal-visual test and their availability during the time in which the interviewers would be in the school. (Students completed a schedule form at the beginning of the semester. A copy of this form is found in Appendix I).

2. Chemistry teachers were notified of which students were to be interviewed and informed students of the date, time and place.

3. Two to three interviewers went to the school for the interview. Two of these were doctoral students in science education, one a masters' degree student. Prior to their going for the first interview a detailed booklet as shown in Appendix J was prepared giving the interview protocol. This protocol was discussed in advance and although there were no formal training sessions, some of the earliest interviews were used as practice sessions. The results from these interviews were not analyzed.

4. Because teachers felt that calling these sessions "interview sessions" might not be well received by students, they were call "feedback sessions". A copy of the procedures as described to the teachers is given in Appendix K. These were slightly modified as follows:

a. Time. Each session lasted approximately 45 minutes, and was conducted, when possible, during study periods. It was necessary at times to have sessions after school and during class time (at the teacher's discretion).

b. Place. The session took place in a separate room away from the chemistry classroom.

c. Supportive materials. Audio-tapes and recorders were needed to record the interview. Students were provided with a periodic table, unlined paper, and a pencil. Originally a calculator was provided. After the first few interviews a decision to disallow the use of a calculator was made. The calculator seemed to inhibit the student from using the "think aloud" technique. He/she pushed buttons instead.

d. Selection of students. Students were selected as described above. In order to encourage participation, $3.00 was paid to each student who participated in the interview. (In one school it was the desire of the principal not to pay students so this was not done. Because of this it was more difficult to get students to participate, particularly after school).

e. Initial instruction to the student. Prior to the feedback session, the students were given the following instructions:

1. The student was told that he/she would be solving problems like he/she had done in class.

2. The student was told that the session was private. The concept of complete privacy was emphasized. The student was insured that nothing said, nor the results of any problems, would be repeated to the teacher or to the classmates of the student.

3. The student was informed that the interviewer was primarily interested in how the problems were solved.

4. Each student was asked if he/she objected to being recorded, and was told that they would not be required to listen to the tape being replayed.

f. During the session the students used a "think aloud" technique. This technique was divided into three sections as follows:

1. Think-Aloud Warm-Up:

    a. The student listened to a short tape of a person solving a problem aloud.

    b. The student was taped while solving a think-aloud problem from Whimbey.

    c. The student was informed of the importance of thinking aloud while solving the problems during the session.

2. Questions Section: Chemistry content questions were asked to establish students' knowledge of chemistry that was considered essential for solving the chemistry problems.

3. Problem Section: Three problems were presented to each student from a pool of items of each type that students tried to solve while thinking aloud. The interviewer prompted students with a general question such as, "What are you thinking now?" when the think aloud process broke down. No hints to the problem solving were given. The interviewers took notes on paper while the student thought aloud. According to other researchers this is supposed to stimulate the think aloud process.

Instruments

Aptitude Measures

The Proportional Reasoning Test and the Verbal-Visual Preference Test were used to classify the students according to their aptitudes.

Approximately half of the students who were interviewed for each of the four topics were considered low in proportional reasoning. The other half was considered high. For the moles unit, students scoring less than or equal to 13 were classified as low whereas students scoring above 13 were classified as high. For the gas laws and stoichiometry units, the cut off point was 11, and for molarity 12.

For the purposes of classification, the scoring of the Verbal-Visual Preference Test was modified to give students a single score. This was done by scoring one point for agreement with items that are imaginal in nature and also one point for disagreement with items that are verbal in nature. This new method is a transformation of the original method by the following function:

$$VVP = EI_C - EV_C + V$$

where VVP is the Verbal-Visual Preference score, I_C represents the number of imagery items scored 'correct' by the Paivio method, V_C represents the number of verbal items scored 'correct' by the Paivio method, and V is the total number of verbal items (a constant = 31). For a subject scoring 22 on the imagery scale and 17 on the verbal scale, the VVP score would be 22-17+31=36. This scoring method allowed for one continuous variable of scores ranging from 0 to 54. It assumes that there is a correlation between the imagery and verbal scores. The actual correlation was .29. This indicates that there is approximately 8% shared variance. Because this amount of variance is fairly low, the decision to use the combined scale was made. It made the selection of students for interviews less complicated than using separate imagery and verbal scores. Students with scores 1 - 34 for the Moles and Gas Laws Units and 1 - 33 for the Stoichiometry and Molarity Units were considered to have high verbal preference. The remaining students were considered to have a high visual or imagery preference.

Interview Questions

A series of questions that were asked in a fixed order were included in each interview immediately following the mathematics problem that the student solved aloud. The reasons for preceding the problems with questions was threefold. It allowed the investigator to determine whether students had the necessary prerequisite skills and a qualitative understanding of the concepts needed to solve the problem; it "tuned-in" the students to the subject matter at hand by reviewing the concepts needed; and, finally it probably set students a little more at ease during the interview since many more could answer the questions successfully than do the problems.

Students were given feedback on the answers to the questions and interviewers prompted them to elicit correct answers after a wrong response or prolonged silence. Answers to the questions were subsequently coded according to whether prompting was necessary to obtain a correct answer.

The number of questions asked varied according to the unit. The moles unit had six questions, gas laws unit seven questions, the stoichiometry unit four questions and the molarity unit five questions. The questions are found in Appendix L.

Interview Problems

Each student was interviewed on how to solve three problems in a given unit. Problems became increasingly more difficult. The first problem was considered to be a one-step problem, the second problem was more complex containing two or more steps. The third problem involved transfer. It was similar to those problems on the delayed posttest that were judged to be transfer items.

Three similar but non-equivalent items were written for each of the above categories. They were considered to be similar in that they contained the same number of steps, and if a chemical equation was involved, the same equation. They were not equivalent in that they tested slightly different concepts, some of which may have been more difficult for the students. For example, the second set of problems used for the stoichiometry interviews were as follows:

2MM - Sodium carbonate (Na_2CO_3) reacts with hydrochloric acid (HCl) to form sodium chloride (NaCl), water (H_2O), and carbon dioxide gas (CO_2) according to the reaction:

$Na_2CO_{3(aq)} + 2\ HCl(aq) \rightarrow 2\ NaCl(aq) + H_2O(l) + CO_2(g)$

How many grams of CO_2 would be produced from 146.0 grams of HCl reacting with sufficient Na_2CO_3?

2MV - Sodium carbonate (Na_2CO_3) reacts with hydrochloric acid (HCl) to form sodium chloride (NaCl), water (H_2O), and carbon dioxide (CO_2) according to the reaction:

$Na_2CO_{3(aq)} + 2\ HCl(aq) \rightarrow 2\ NaCl(aq) + H_2O(l) + CO_2(g)$

How many liters of CO_2 (measured at STP) would be produced from 146.0 grams of HCl reacting with sufficient Na_2CO_3?

2MP - Sodium carbonate (Na_2CO_3) reacts with hydrochloric acid (HCl) to form sodium chloride (NaCl), water (H_2O), and carbon dioxide gas (CO_2) according to the reaction:

$$Na_2CO_{3(aq)} + 2\ HCl(aq) \rightarrow 2\ NaCl(aq) + H_2O(l) + CO_2(g)$$

How many molecules of CO_2 would be produced from 146.0 grams of HCl reacting with sufficient Na_2CO_3?

In every case, the same equation was used. The first problem is a mass-mass problem, the second is a volume-mass problem and the third is a particle-mass problem.

The problems were typed on individual 8" x 5" cards. The interviewers randomly selected 1 problem from each of the three sets of cards. These three problems were then presented individually by the interviewer to the student being interviewed.

This resulted in the distribution of problems as shown in Table 112. Problems are given in Appendix L.

Coding Protocol

The tapes were coded using a protocol adapted from one used by Nurrenbern (1979). The same general categories of reading/organizing, recall, production, strategy, structural errors, evaluation, comments about solution and executive errors were included. In addition, a section on the questions was added.

Some categories were modified slightly because it was felt that they were not suitable for the category. For example, under Reading/Organizing, the category "Says he does not understand the problem" was deleted because it was felt it would lead to spuriously high results - it did not indicate an organizing skill.

The production category was modified by organizing statements into those approaches thought to be systematic versus non-systematic. A "No answer

Table 112

Distribution of Problems for Interviews

Unit	Problems					
	Set 1		Set 2		Set 3	
	Problem Code No.	Times Used	Problem Code No.	Times Used	Problem Code No.	Times Used
Moles	M	24	VM	23	VA	23
	V	25	MMo	29	MA	24
	Mo	25	MoV	22	VM	19
Gas Laws	TP	25	TVP	18	M-TV	20
	TV	18	TPV	20	M+TV	21
	PV	21	PVT	26	MPV	23
Stoichiometry	M	18	MM	26	HH	22
	V	27	MV	23	SS1	24
	P	21	MP	17	SS2	20
Molarity	M1	18	MoD	25	WA	22
	G	23	MoC	16	GA1	23
	Mo	23	MV	23	GA2	19

given" category was added to allow for cases in which students did not work enough of the problem to allow a judgement to be made on how the problem was being solved. Several categories under "production" were moved to "structural errors".

The "structural error" section used by Nurrenbern had been devised for her particular study of stoichiometry limiting-reagent problems. Because this was inappropriate for many of the problems that had to be coded in this study, it was revised to make this section more inclusive. This modification was used in the moles problems. After using this same schema for coding the problems in the gas laws, stoichiometry and molarity units, it was recognized that some data were being lost. Three new coding sheets for the structural errors for each of the remaining topics (gas laws, stoichiometry, and molarity) were then devised.

Modifications were also made of the description of the coding form used by Nurrenbern. In some cases the description given was not comprehensive enough to cover the wide range of responses to be coded consistently by the same reviewer or by another reviewer. The general coding form, the structural errors coding form, and the coding form descriptions are given in Appendix M .

All of the tapes were coded three times, twice by the same rater and then checked by the principal investigator. Comments made by the interviewer during the interview as well as the sheet used by the student for calculation were used in the coding process. The rater, a doctoral student who was a former middle school science teacher, listened to an individual tape and coded it on the general coding sheet. Between one and three weeks later, he listened to the tape again and coded it independently. The principal investigator then compared the two coding sheets while listening to the tape and made any appropriate additions or resolved conflicting codes. The reliability of the coding

Table 113

Reliability of Coding of Interviews Using Kendall's Coefficient of Concordance

	Moles		Gas Laws		Stoichiometry		Molarity	
General Form Categories	Coefficient W	P	Coefficient W	P	Coefficient W	P	Coefficient W	P
*Reading/Organizing	.95	.00	.98	.00	.92	.00	.93	.00
Systemmatic Approach	.97	.00	.97	.00	.98	.00	1.00	.00
Approach Taught	.91	.00	.95	.00	1.00	.00	1.00	.00
Arithmetic Algorithm	.93	.00	.95	.00	.92	.00	1.00	.00
Nonsystemmatic Approach	.95	.00	.86	.00	.90	.00	1.00	.00
No Answer Given	.82	.00	.97	.00	.90	.00	1.00	.00
Algorithmic Only	.96	.00	.96	.00	.95	.00	.97	.00
Algorithmic/Reasoning Strategy	.95	.00	.97	.00	.97	.00	1.00	.00
Random Trial and Error	.95	.00	.74	.01	.87	.00	.91	.00
Misinterprets Problem	.54	.03	1.00	.00	.33	.45	1.00	.00
Disregards Information Given	.83	.00	.78	.00	.67	.01	1.00	.00
Disregards Information Generated	.49	.06	1.00	.00	1.00	.00	.70	.01
Misapplies Information	.83	.00	.94	.00	.52	.09	1.00	.00
Needed Information Not Generated	.33	.46	.98	.00	.43	.21	1.00	.00
*Evaluation	.96	.00	.92	.00	.92	.00	.99	.00
*Comments About Solution	.92	.00	.99	.00	.99	.00	1.00	.00
*Executive Errors	.95	.00	1.00	.00	.78	.00	.85	.00
Problems Correct	1.00	.00	1.00	.00	.97	.00	1.00	.00
Problems Incorrect	.99	.00	1.00	.00	.98	.00	1.00	.00
Questions Correct	.98	.00	1.00	.00	1.00	.00	1.00	.00
Questions Incorrect	.98	.00	1.00	.00	1.00	.00	1.00	.00
Questions C1	.95	.00	1.00	.00	.95	.00	.33	.44
Questions C2	.92	.00	1.00	.00	.98	.00	1.00	.00
Questions C3	1.00	.00	1.00	.00	1.00	.00	1.00	.00
Questions C4	1.00	.00	1.00	.00	1.00	.00	1.00	.00
Structural Errors Sheet								
*Problem 1 C1	X[1]	X	1.00	.04	1.00	.04	.94	.05
*Problem 1 C2	X	X	1.00	.04	1.00	.04	1.00	.04
*Problem 2 C1	X	X	.93	.05	.85	.08	.84	.09
*Problem 2 C2	X	X	1.00	.04	1.00	.04	1.00	.04
*Problem 3 C1	X	X	.96	.04	1.00	.04	.95	.05
*Problem 3 C2	X	X	.90	.06	1.00	.04	1.00	.04
*Problem 3 C3	X	X	.92	.06	1.00	.04	1.00	.04

*Section is summed over several codes.

[1] Not applicable

system between the three ratings (two by the one rater, one by the principal investigator) using Kendall's Coefficient of Concordance ranged from 3.3 to 1.00 only 4% had a probability level exceeding .05.

The original rater did not use the specially prepared structural error sheet because his background in chemistry was somewhat limited. These were coded by the principal investigator (a chemistry educator) and checked by an experienced chemistry teacher whose students participated in the study. Reliabilities ranged from .84 to 1.00.

A summary of the reliability of the coding of the interviews is found in Table 113.

Hypotheses

The following hypotheses were tested using data from the interviews:

1. There are no significant differences in chemistry problem solving strategies used by students having verbal or visual preferences for learning.
2. There are no significant differences in chemistry problem solving strategies used by students of high and low proportional reasoning ability.
3. There are no significant differences in chemistry problem solving strategies used by students considered successful problem solvers versus unsuccessful ones.
4. There are no significant differences in chemistry problem solving strategies used by students according to the method taught to solve the problems.
5. There are no significant differences in chemistry problem solving strategies used by students who solved the problem correctly versus those who did not.
6. There are no differences in the number of questions a student answers successfully according to verbal-visual preference, proportional reasoning ability, success in problem solving, the method taught in learning problem solving, and the number of problems solved correctly.

Statistical Analyses

Hypotheses one through five were analyzed using three different statistical methods. In cases where only frequencies were available, chi-square analyses were used. This method was used for the following: reading/organizing codes, mneumonic codes, production codes, strategy codes, and structural error codes.

In cases where data were summed for given categories, Kruskal-Wallis one way analyses of variance were used when the data were not normally distributed and three groups were present. (This was determined using the Kolmogorov-Smirnov goodness of fit test.) Mann-Whitney U Tests were used in cases where data were not normally distributed and only two groups were present. Data were summed for the following: reading/organizing, evaluation, comments about solution, executive errors, total number of questions correct, number of non-prompted questions correct, number of problems correct and for all categories previously analyzed using the chi-square when they were summed over problems. A summary of tests used for each analysis is given in Table 114.

Table 114

Tests of Significance Used With Interview Data

	Verbal-Visual Preference		Proportional Reasoning Ability		Success/Unsuccess 3 Levels Test		Teaching Strategy		Problems Correct/ Incorrect	
	P	T	P	T	P	T	P	T	P	T
Reading/Organizing	3	3	3	3	2	2	2	2	3	2
Rereads or Stating	3	3	3	3	2	2	2	2	3	2
Mneumonics	3	3	3	3	2	2	2	2	3	2
Production										
Systematic	1	3	1	3	1	2	1	2	1	2
Approach Taught	1	3	1	3	1	2	1	2	1	2
Arithmetic	1	3	1	3	1	2	1	2	1	2
Nonsystem	1	3	1	3	1	2	1	2	1	2
No Answer	1	3	1	3	1	2	1	2	1	2
Strategy										
Algorithmic	1	3	1	3	1	2	1	2	1	2
Alg/Reasoning	1	3	1	3	1	2	1	2	1	2
Random T & E	1	3	1	3	1	2	1	2	1	2
Structural Error										
Misinterprets	1	3	1	3	1	2	1	2	1	2
Disregards given	1	3	1	3	1	2	1	2	1	2
Disregards gen	1	3	1	3	1	2	1	2	1	2
Misapplies	1	3	1	3	1	2	1	2	1	2
Not generate	1	3	1	3	1	2	1	2	1	2
Evaluation	3	3	3	3	2	2	2	2	3	2
Comments about Solution	3	3	3	3	2	2	2	2	3	2
Executive Errors	3	3	3	3	2	2	2	2	3	2
Problems Correct	X	3	X	3	X	2	X	2		2
Questions Correct	X	3	X	3	X	2	X	2		2
Questions w/o Prompting	X	3	X	3	X	2	X	2		2
Structural Errors										
Section 1	1	3	1	3	1	2	1	2	1	2
Section 1	1	3	1	3	1	2	1	2	1	2
Section 2	1	3	1	3	1	2	1	2	1	2
Section 2	1	3	1	3	1	2	1	2	1	2
Section 3	1	3	1	3	1	2	1	2	1	2
Section 3	1	3	1	3	1	2	1	2	1	2
Section 3	1	3	1	3	1	2	1	2	1	2

1=Chi Square
2=Kruskal-Wallis
3=Mann-Whitney
X=Inappropriate Analysis

Results

Hypothesis 1

There are no significant differences in chemistry problem solving strategies used by students having verbal or visual preferences for learning.

In order to test this hypothesis students were divided into two groups according to their scores on the modified Paivio verbal-visual preference test. These groupings are summarized in Table 115. Results of the analysis used to test the hypothesis for each of the four chemistry topics are summarized in Table 116. Tables 117-120 give more detailed information for analyses where significant differences were found.

Findings show that students' verbal or visual preferences as measured by the modified Paivio instrument were generally not related to their problem solving strategies. Table 117 indicates that visual students tended to show more overt signs of reading/organizing skills and reading/stating the problem than verbal students on the moles problem 3. There is little educational significance to this finding, however, as no significant differences were found for the other moles problems or for problems from the other three units.

Similar results are found in Table 118. More visual students tended to use only algorithmic strategies rather than algorithmic/reasoning strategies, and they also had a greater tendency to misapply information. Results again hold for only the moles unit.

On the other hand, visual students made fewer errors in balancing equations as shown in Table 119- structural error 1 - 1. (Structural errors varied according to units so the fact that structural error 1 - 1 is not significant across the units has no bearing on these results.)

Table 120 shows that visual students also showed greater evidence for using the approach taught in their packet to solve the problems on molarity. This was not evident for problems in the other three units.

Table 116
Summary of Significant Findings: Verbal-Visual Preference

	Moles				Gas Laws				Stoichiometry				Molarity			
Protocol Categories	P1[a]	P2[b]	P3[c]	T[d]	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Reading/Organizing			478[e] .04[f]													
Rereads or Stating[g]			482 .02													
Mneumonics																
Production																
Systemmatic																
Approach Taught																370 .02
Arithmetic																
Nonsystemmatic																
No Answer																
Strategy																
Algorithmic				483 .05												
Alg/Reasoning																
Random T & E																
Structural Error																
Misinterprets																
Disregards given																
Disregards gen																
Misapplies				540 .01												
Not generate																

Table 116 (continued)

Summary of Significant Findings: Verbal-Visual Preference

	Moles				Gas Laws				Stoichiometry				Molarity			
Protocol Categories	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Evaluation																
*Comments about Solution																
*Executive Errors																
*Problems Correct	X[i]	X	X		X	X	X		X	X	X		X	X	X	
*Questions Correct	X	X	X		X	X	X		X	X	X		X	X	X	
*Question w/o Prompting	X	X	X		X	X	X		X	X	X		X	X	X	
Structural Errors																
Section[h] 1 - 1	X	X	X	X		X	X	X	9.86 .02	X	X	X		X	X	X
Section 1 - 2	X	X	X	X		X	X	X		X	X	X		X	X	X
Section 2 - 1	X	X	X	X	X		X	X	X		X	X	X		X	X
Section 2 - 2	X	X	X	X	X		X	X	X		X	X	X		X	X
Section 3 - 1	X	X	X	X	X	X		X	X	X		X	X	X		X
Section 3 - 2	X	X	X	X	X	X		X	X	X		X	X	X		X
Section 3 - 3	X	X	X	X	X	X		X	X	X		X	X	X		X

*Category sum

[a] Problem 1

[b] Problem 2

[c] Problem 3

[d] Sum of Problems 1, 2 & 3

[e] Statistic

[f] Probability level

[g] Sum of rereads and restates subcategories

[h] Section on supplementary coding sheet

[i] Not meaningful

Table 115

Distribution of Students According to Verbal-Visual Preference

Unit	Verbal			Visual		
	Range	X	N	Range	X	N
Moles	20-34	29.4	36	35-48	39.8	36
Gas Laws	24-34	29.0	34	35-48	39.6	30
Stoichiometry	16-33	27.7	33	34-44	37.9	33
Molarity	16-33	27.8	31	34-45	38.3	33

Table 117

Interview Data Analyses: Moles - Problem 3
Verbal-Visual Preference

Verbal-Visual	Reading/Organizing Skills					Rereading/Stating Problem			
	0	1	2	3	Total	0	1	2	Total
Verbal	15[a]	17	2	2	36	29	7	0	36
	41.7[b]	47.2	5.6	5.6	50.0	80.6	19.4	0	50.0
	62.5[c]	53.1	15.4	66.7	(31.8)[e]	59.2	31.8	0	(31.9)
	20.8[d]	23.6	2.8	2.8		40.3	9.7	0	
Visual	9	15	11	1	36	20	15	1	36
	25.0	41.7	30.6	2.8	50.0	55.6	41.7	2.8	50.0
	37.5	46.9	84.6	33.3	(41.2)	40.8	68.2	100.0	(41.1)
	12.5	20.8	15.3	1.4		27.8	20.8	1.4	
Total	24	32	13	3	72	49	22	1	72
	33.3	44.4	18.1	4.2	100.0	68.1	30.6	1.4	100.0

Mann-Whitney U	478	Mann-Whitney	482
Wilcoxon Rank Sum W	1144	Wilcoxon Rank Sum W	1148
Z	-2.05	Z	-2.30
Significance	.04	Significance	.02

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[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[e] Mean rank

Table 118

Interview Data Analyses: Moles - Total Verbal-Visual Preference

Verbal-Visual	Algorithmic Strategy Only 0	1	2	3	Total	Misapplies Information Generated 0	1	Total
	14	10	5	7	36	36	0	36
	38.9	27.8	13.9	19.4	50.0	100.0	0	50.0
Verbal	66.7	58.8	26.3	46.7	(31.9)	54.5	0	(33.5)
	19.4	13.9	6.9	9.7		50.0	0	
	7	7	14	8	36	30	6	36
	19.4	19.4	38.9	22.2	50.0	83.3	16.7	50.0
	33.3	41.2	73.7	53.3	(41.1)	45.5	100.0	(39.5)
Visual	9.7	9.7	19.4	11.1		41.7	8.3	
Total	21	17	19	15	72	66	6	72
	29.2	23.6	26.4	20.8	100.0	91.7	8.3	100.0

Mann-Whitney U	483	Mann-Whitney U	540
Wilcoxon Rank Sum W	1149	Wilcoxon Rank Sum W	1206
Z	-1.92	Z	-2.54
Significance	.05	Significance	.01

Table 119

Interview Data Analyses: Stoichiometry - Problem 1
Verbal-Visual Preference

Verbal-Visual	Structural Error 1 - 1 0	 1	 2	 3	 Total
Verbal	0[a]	7	10	16	33
	0[b]	21.2	30.3	48.5	50.0
	0[c]	30.4	76.9	57.1	
	0[d]	10.6	15.2	24.2	
Visual	2	16	3	12	33
	6.1	48.5	9.1	36.4	50.0
	100.0	69.6	23.1	42.9	
	3.0	24.2	4.5	18.2	
Total	2	23	13	28	66
	3.0	34.8	19.7	42.4	100.0

Chi Square	9.86
df	3
V	.39[f]
Significance	.02

---

[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[f] Cramer's V

Table 120

Interview Data Analyses: Molarity - Total Verbal-Visual Preference

Verbal-Visual	Approach Taught 0	1	2	3	Total
Verbal	26	2	0	3	31
	83.9	6.5	0	9.7	48.4
	59.1	25.0	0	50.0	(28.0)
	40.6	3.1	0	4.7	
Visual	18	6	6	3	33
	54.5	18.2	18.2	9.1	51.6
	40.9	75.0	100.0	50.0	(36.8)
	28.1	9.4	9.4	4.7	
Total	44	8	6	6	64
	68.8	12.5	9.4	9.4	100.0

Mann-Whitney U	370
Wilcoxon Rank Sum W	866
Z	-2.31
Significance	.02

Hypothesis 2

There are no significant differences in chemistry problem solving strategies used by students of high or low proportional reasoning ability.

In order to test this hypothesis students were divided into two groups according to their proportional reasoning ability. The resulting groups are described in Table 121. Results of the analyses used to test the hypothesis are summarized in Table 122 and details for significant findings are found in Tables 123-155.

All results will be discussed in terms of the protocol categories across the four units.

Rereading or stating. Molarity, problem 3 only, Table 149. Students with high proportional reasoning ability reread/stated more frequently.

Mneumonics. Gas Laws, problem 1 only, Table 131. Students with high proportional reasoning ability used mneumonic notation more frequently.

Systemmatic approach. Moles, problems 1, 2, total, and stoichiometry, problems 1, 2, 3, total, (Tables 135,138,140,142). All tables indicate that high proportional reasoning students used a more systemmatic approach.

Nonsystemmatic approach. Stoichiometry, problem 2, (Table 138), and molarity, total, (Table 151). Nonsystemmatic approaches were used by students of low proportional reasoning ability.

No answer given. Moles, total, (Table 126), and stoichiometry, problem 1, (Table 135). Low proportional reasoning students more frequently did not give an answer.

Algorithmic strategy. Gas Laws, problem 3, total (Tables 133, 134) and molarity, total, (Table 149). Low proportional reasoning students tended to use only algorithmic strategies.

Algorithmic/reasoning strategy. Moles, problems 2, 3, total, (Tables 124, 125, 127), gas laws, all analyses, (Tables 131, 132, 133, 135), stoichiometry,

Table 121

Distribution of Students According to Proportional Reasoning Ability (PPRT)

Unit	Low PPRT			High PPRT		
	Range	X	N	Range	X	N
Moles	6-13	10.0	36	14-21	17.4	35
Gas Laws	5-11	9.0	33	12-21	15.5	31
Stoichiometry	5-11	8.9	31	12-21	16.7	35
Molarity	6-12	9.3	29	13-21	16.3	35

Table 122

Summary of Significant Findings: Proportional Reasoning Ability

Protocol Categories	Moles				Gas Laws				Stoichiometry				Molarity			
	P1[a]	P2[b]	P3[c]	T[d]	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Reading/Organizing																
Rereads or Stating[g]															375[e] .05[f]	
Mneumonics					374 .008											
Production																
Systemmatic	6.90 .009	4.12 .04		445 .02					6.21 .01	7.51 .006	5.00 .03	314 .002				
Approach Taught																
Arithmetic																
Nonsystemmatic										4.87 .03						623 .05
No Answer				755 .02					4.29 .04							
Strategy																
Algorithmic							5.31 .02	671 .02								662 .03
Alg/Reasoning		8.09 .004	4.91 .03	412 .004	3.96 .05	3.94 .05	5.58 .02	314 .005	12.25 .0005	10.01 .002	8.33 .004	300 .0002	16.79 <.0001	7.59 .006	4.73 .03	229 <.0001
Random T & E				771 .05						5.61 .02		670 .05	4.77 .03			645 .02
Structural Error																
Misinterprets																
Disregards given																624 .02
Disregards gen																
Misapplies																
Not generate																

Table 122 (continued)

Summary of Significant Findings: Proportional Reasoning Ability

	Moles				Gas Laws				Stoichiometry				Molarity			
Protocol Categories	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Evaluation																
*Comments about Solution	761 .05		827 .008	844 .009	632 .03				800 .0002	702 .02	734 .003	845 .0001			637 .04	675 .02
*Executive Errors																
*Problems Correct	X[i]	X	X	330 .0003	X	X	X		X	X	X	391 .03	X	X	X	237 <.0001
*Questions Correct	X	X	X	402 .005	X	X	X		X	X	X	404 .04	X	X	X	236 .0001
*Question w/o Prompting	X	X	X	272 <.0001	X	X	X		X	X	X		X	X	X	240 .0002
Structural Errors																
Section[h] 1 - 1	X	X	X	X		X	X	X	9.98 .02	X	X	X	20.01 .006	X	X	X
Section 1 - 2	X	X	X	X		X	X	X		X	X	X	26.89 .0002	X	X	X
Section 2 - 1	X	X	X	X	X		X	X	X		X	X	X		X	X
Section 2 - 2	X	X	X	X	X		X	X	X		X	X	X		X	X
Section 3 - 1	X	X	X	X	X	X		X	X	X		X	X	X		X
Section 3 - 2	X	X	X	X	X	X		X	X	X		X	X	X	12.93 .01	X
Section 3 - 3	X	X	X	X	X	X		X	X	X	13.44 .004	X	X	X	9.28 .03	X

*Category sum

[a] Problem 1

[b] Problem 2

[c] Problem 3

[d] Sum of Problems 1, 2 & 3

[e] Statistic

[f] Probability level

[g] Sum of rereads and restates subcategories

[h] Section on supplementary coding sheet

[i] Not meaningful

Table 123

Interview Data Analyses: Moles - Problem 1
Proportional Reasoning Ability

Proportional Reasoning Ability	Systematic Approach 0	Systematic Approach 1	Systematic Approach Total	Comments about Solution 0	Comments about Solution 1	Comments about Solution 2	Comments about Solution 3	Comments about Solution Total
	12[a]	24	36	23	9	3	1	36
	33.3[b]	66.7	50.7	63.9	25.0	8.3	2.8	50.7
Low	85.7[c]	42.1		44.2	60.0	100.0	100.0	(39.7)
	16.9[d]	33.8		32.4	12.7	4.2	1.4	
	2	33	35	29	6	0	0	35
	5.7	94.3	49.3	82.9	17.1	0	0	49.3
High	14.3	57.9		55.8	40.0	0	0	(32.2)
	2.8	46.5		40.8	8.5	0	0	
Total	14	57	71	52	15	3	1	71
	19.7	80.3	100.0	73.2	21.1	4.2	1.4	100.0
	Chi Square	6.90			Mann-Whitney U		761	
	df	1			Wilcoxon Rank Sum W		1128	
	Phi	.35			Z		1.96	
	Significance	.009			Significance		.05	

[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage

Table 124

Interview Data Analyses: Moles - Problem 2
Proportional Reasoning Ability

Proportional Reasoning Ability	Systemmatic Approach 0	Systemmatic Approach 1	Systemmatic Approach Total	Algorithmic Reasoning Strategy 0	Algorithmic Reasoning Strategy 1	Algorithmic Reasoning Strategy Total
Low	11	25	36	30	6	36
	30.6	69.4	50.7	83.3	16.7	50.7
	78.6	43.9		63.8	25.0	
	15.5	35.2		42.3	8.5	
High	3	32	35	17	18	35
	8.6	91.4	49.3	48.6	51.4	49.3
	21.4	56.1		36.2	75.0	
	4.2	45.1		23.9	25.4	
Total	14	57	71	47	24	71
	19.7	80.3	100.0	66.2	33.8	100.0
	Chi Square	4.12		Chi Square	8.09	
	df	1		df	1	
	Phi	.28		Phi	.37	
	Significance	.04		Significance	.004	

Table 125

Interview Data Analyses: Moles - Problem 3
Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Reasoning Strategy 0	1	Total	Comments about Solution 0	1	2	Total
Low	31	5	36	16	18	2	36
	86.1	13.9	50.7	44.4	50.0	5.6	50.7
	59.6	26.3		38.1	66.7	100.0	(41.5)
	43.7	7.0		22.5	25.4	2.8	
High	21	14	35	26	9	0	35
	60.0	40.0	49.3	74.3	25.7	0	49.3
	40.4	73.7		61.9	33.3	0	(30.4)
	29.6	19.7		36.6	12.7	0	
Total	52	19	71	42	27	2	71
	73.2	26.8	100.0	59.2	38.0	2.8	100.0
	Chi Square		4.91	Mann-Whitney U			827
	df		1	Wilcoxon Rank Sum W			1063
	Phi		.29	Z			2.64
	Significance		.03	Significance			.008

Table 126

Interview Data Analyses: Moles - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Systematic Approach 0	1	2	3	Total	No Answer Given 0	1	2	3	Total
Low	6[a]	7	8	15	36	27	5	2	2	36
	16.7[b]	19.4	22.2	41.7	50.7	75.0	13.9	5.6	5.6	50.7
	85.7[c]	87.5	40.0	41.7	(30.9)[e]	45.0	71.4	100.0	100.0	(39.5)
	8.5[d]	9.9	11.3	21.1		38.0	7.0	2.8	2.8	
High	1	1	12	21	35	33	2	0	0	35
	2.9	2.9	34.3	60.0	49.3	94.3	5.7	0	0	49.3
	14.3	12.5	60.0	58.3	(41.3)	55.0	28.6	0	0	(32.4)
	1.4	1.4	16.9	29.6		46.5	2.8	0	0	
Total	7	8	20	36	71	60	7	2	2	71
	9.9	11.3	28.2	50.7	100.0	84.5	9.9	2.8	2.8	100.0

	Systematic Approach		No Answer Given
Mann-Whitney U	445	Mann-Whitney U	755
Wilcoxon Rank Sum W	1445	Wilcoxon Rank Sum W	1134
Z	-2.31	Z	2.29
Significance	.02	Significance	.02

[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[e] Mean rank

Table 127

Interview Data Analyses: Moles - Total
Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Reasoning Strategy					Use of Random Trial and Error				
	0	1	2	3	Total	0	1	2	3	Total
Low	28	3	1	4	36	21	8	5	2	36
	77.8	8.3	2.8	11.1	50.7	58.3	22.2	13.9	5.6	50.7
	65.1	37.5	11.1	36.4	(30.0)	42.9	61.5	100.0	50.0	(39.9)
	39.4	4.2	1.4	5.6		29.6	11.3	7.0	2.8	
High	15	5	8	7	35	28	5	0	2	35
	42.9	14.3	22.9	20.0	49.3	80.0	14.3	0	5.7	49.3
	34.9	62.5	88.9	63.6	(42.2)	57.1	38.5	0	50.0	(32.0)
	21.1	7.0	11.3	9.9		39.4	7.0	0	2.8	
Total	43	8	9	11	71	49	13	5	4	71
	60.6	11.3	12.7	15.5	100.0	69.0	18.3	7.0	5.6	100.0

Mann-Whitney U	412	Mann-Whitney U	771
Wilcoxon Rank Sum W	1477	Wilcoxon Rank Sum W	1119
Z	-2.85	Z	1.99
Significance	.004	Significance	.05

Table 128

Interview Data Analyses: Moles - Total
Proportional Reasoning Ability

Proportional Reasoning Ability	Comments about Solution							Problems Correct				
	0	1	2	3	4	5	Total	0	1	2	3	Total
Low	12	7	5	9	2	1	36	20	8	6	2	36
	33.3	19.4	13.9	25.0	5.6	2.8	50.7	55.6	22.2	16.7	5.6	50.7
	40.0	36.8	62.5	81.8	100.0	100.0	(42.0)	76.9	53.3	26.1	28.6	(27.7)
	16.9	9.9	7.0	12.7	2.8	1.4		28.2	11.3	8.5	2.8	
High	18	12	3	2	0	0	35	6	7	17	5	35
	51.4	34.3	8.6	5.7	0	0	49.3	17.1	20.0	48.6	14.3	49.3
	60.0	63.2	37.5	18.2	0	0	(29.9)	23.1	46.7	73.9	71.4	(44.6)
	25.4	16.9	4.2	2.8	0	0		8.5	9.9	23.9	7.0	
Total	30	19	8	11	2	1	71	26	15	23	7	71
	42.3	26.8	11.3	15.5	2.8	1.4	100.0	36.6	21.1	32.4	9.9	100.0

Mann-Whitney U	844	Mann-Whitney U	330
Wilcoxon Rank Sum W	1045	Wilcoxon Rank Sum W	1560
Z	2.60	Z	-3.62
Significance	.009	Significance	.0003

Table 129

Interview Data Analyses: Moles Total
Proportional Reasoning Ability

Proportional Reasoning Ability	Questions Correct					
	2	3	4	5	6	Total
Low	4	6	8	5	13	36
	11.1	16.7	22.2	13.9	36.1	50.7
	100.0	85.7	66.7	33.3	39.4	(29.7)
	5.6	8.5	11.3	7.0	18.3	
High	0	1	4	10	20	35
	0	2.9	11.4	28.6	57.1	49.3
	0	14.3	33.3	66.7	60.6	(42.5)
	0	1.4	5.6	14.1	28.2	
Total	4	7	12	15	33	71
	5.6	9.9	16.9	21.1	46.5	100.0

Mann-Whitney U	402
Wilcoxon Rank Sum W	1488
Z	-2.79
Significance	.005

Table 130

Interview Data Analyses: Moles - Total
Proportional Reasoning Ability

Proportional Reasoning Ability	Questions Correct Without Prompting							
	0	1	2	3	4	5	6	Total
Low	3	3	13	6	6	5	0	36
	8.3	8.3	36.1	16.7	16.7	13.9	0	50.7
	100.0	75.0	81.3	50.0	46.2	29.4	0	(26.1)
	4.2	4.2	18.3	8.5	8.5	7.0	0	
High	0	1	3	6	7	12	6	35
	0	2.9	8.6	17.1	20.0	34.3	17.1	49.3
	0	25.0	18.8	50.0	53.8	70.6	100.0	(46.2)
	0	1.4	4.2	8.5	9.9	16.9	8.5	
Total	3	4	16	12	13	17	6	71
	4.2	5.6	22.5	16.9	18.3	23.9	8.5	100.0

Mann-Whitney U	272
Wilcoxon Rank Sum W	1618
Z	-4.19
Significance	< .0001

Table 131

Interview Data Analyses: Gas Laws - Problem 1
Proportional Reasoning Ability

Proportional Reasoning Ability	Use of Mneumonic Notation			Algorithmic Reasoning Strategy			Comments about Solution		
	0	1	Total	0	1	Total	0	1	Total
	11	2	33	24	9	33	21	12	33
	33.3	66.7	51.6	72.7	27.3	51.6	63.6	36.4	51.6
Low	84.6	43.1	(28.3)	63.2	34.6		43.8	75.0	(36.1)
	17.2	34.4		37.5	14.1		32.8	18.8	
	2	29	31	14	17	31	27	4	31
	6.5	93.5	48.4	45.2	54.8	48.4	87.1	12.9	48.4
High	15.4	56.9	(36.9)	36.8	65.4		56.3	25.0	(28.6)
	3.1	45.3		21.9	26.6		42.2	6.3	
Total	13	51	64	38	26	64	48	16	64
	20.3	79.7	100.0	59.4	40.6	100.0	75.0	25.0	100.0

Mann-Whitney U	374	Chi Square	3.96	Mann-Whitney U	632
Wilcoxon Rank Sum W	1145	df	1	Wilcoxon Rank Sum W	887
Z	-2.65	Phi	.28	Z	2.15
Significance	.008	Significance	.05	Significance	.03

Table 132

Interview Data Analyses: Gas Laws - Problem 2
Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Reasoning Strategy		
	0	1	Total
	23	10	33
	69.7	30.3	51.6
Low	63.9	35.7	
	35.9	15.6	
	13	18	31
	41.9	58.1	48.4
High	36.1	64.3	
	20.3	28.1	
Total	36	28	64
	56.3	43.8	100.0

Chi Square	3.94
df	1
Phi	.28
Significance	.05

Table 133

Interview Data Analyses: Gas Laws - Problem 3
Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Strategy Only			Algorithmic Reasoning Strategy		
	0	1	Total	0	1	Total
Low	24	9	33	31	2	33
	72.7	27.3	51.6	93.9	6.1	51.6
	44.4	90.0		59.6	16.7	
	37.5	14.1		48.4	3.1	
High	30	1	31	21	10	31
	96.8	3.2	48.4	67.7	32.3	48.4
	55.6	10.0		40.4	83.3	
	46.9	1.6		32.8	15.6	
Total	54	10	64	52	12	64
	84.4	15.6	100.0	81.3	18.8	100.0
	Chi Square		5.31	Chi Square		5.58
	df		1	df		1
	Phi		.33	Phi		.34
	Significance		.02	Significance		.02

Table 134

Interview Data Analyses: Gas Laws - Total
Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Strategy Only					Algorithmic Reasoning Strategy				
	0	1	2	3	Total	0	1	2	3	Total
Low	10	6	11	6	33	20	6	6	1	33
	30.3	18.2	33.3	18.2	51.6	60.6	18.2	18.2	3.0	51.6
	37.0	60.0	52.4	100.0	(37.3)	66.7	60.0	37.5	12.5	(26.5)
	15.6	9.4	17.2	9.4		31.3	9.4	9.4	1.6	
High	17	4	10	0	31	10	4	10	7	31
	54.8	12.9	32.3	0	48.4	32.3	12.9	32.3	22.6	48.4
	63.0	40.0	47.6	0	(27.4)	33.3	40.0	62.5	87.5	(38.9)
	26.6	6.3	15.6	0		15.6	6.3	15.6	10.9	
Total	27	10	21	6	64	30	10	16	8	64
	42.2	15.6	32.8	9.4	100.0	46.9	15.6	25.0	12.5	100.0

Mann-Whitney U	671	Mann-Whitney U	314
Wilcoxon Rank Sum W	848	Wilcoxon Rank Sum W	1206
Z	2.28	Z	-2.84
Significance	.02	Significance	.005

Table 135

Interview Data Analyses: Stoichiometry - Problem 1 Proportional Reasoning Ability

Proportional Reasoning Ability	Systemmatic Approach			No Answer Given		
	0	1	Total	0	1	Total
Low	14 45.2 73.7 21.2	17 54.8 36.2 25.8	31 47.0	24 77.4 41.4 36.4	7 22.6 87.5 10.6	31 47.0
High	5 14.3 26.3 7.6	30 85.7 63.8 45.5	35 53.0	34 97.1 58.6 51.5	1 2.9 12.5 1.5	35 53.0
Total	19 28.8	47 71.2	66 100.0	58 87.9	8 12.1	66 100.0
	Chi Square		6.21	Chi Square		4.29
	df		1	df		1
	Phi		.34	Phi		.30
	Significance		.01	Significance		.04

Table 136

Interview Data Analyses: Stoichiometry - Problem 1
Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Reasoning Strategy 0	1	Total	Comments About Solution 0	1	2	Total
Low	29	2	31	8	21	2	31
	93.5	6.5	47.0	25.8	67.7	6.5	47.0
	61.7	10.5		24.2	67.7	100.0	(41.8)
	43.9	3.0		12.1	31.8	3.0	
High	18	17	35	25	10	0	35
	51.4	48.6	53.0	71.4	28.6	0	53.0
	38.3	89.5		75.8	32.3	0	(26.1)
	27.3	25.8		37.9	15.2	0	
Total	47	19	66	33	31	2	66
	71.2	28.8	100.0	50.0	47.0	3.0	100.0

Chi Square	12.25	Mann-Whitney U	800
df	1	Wilcoxon Rank Sum W	1296
Phi	.46	Z	3.77
Significance	.0005	Significance	.0002

Table 137

Interview Data Analyses: Stoichiometry - Problem 1
Proportional Reasoning Ability

Proprotional Reasoning Ability	Structural Error - 1 0	 1	 2	 3	 Total
	2	8	3	18	31
	6.5	25.8	9.7	58.1	47.0
Low	100.0	34.8	23.1	64.3	
	3.0	12.1	4.5	27.3	
	0	15	10	10	35
	0	42.9	28.6	28.6	53.0
High	0	65.2	76.9	35.7	
	0	22.7	15.2	15.2	
Total	2	23	13	28	66
	3.0	34.8	19.7	42.4	100.0

Chi Square	9.98
df	3
Phi	.39
Significance	.02

Table 138

Interview Data Analyses: Stoichiometry - Problem 2
Proportional Reasoning Ability

Proportional Reasoning Ability	Systemmatic Approach			Nonsystemmatic Approach			Algorithmic Reasoning Strategy		
	0	1	Total	0	1	Total	0	1	Total
Low	15	16	31	22	9	31	28	3	31
	48.4	51.6	47.0	71.0	29.0	47.0	90.3	9.7	47.0
	75.0	34.8		40.0	81.8		60.9	15.0	
	22.7	24.2		33.3	13.6		42.4	4.5	
High	5	30	35	33	2	35	18	17	35
	14.3	85.7	53.0	94.3	5.7	53.0	51.4	48.6	53.0
	25.0	65.2		60.0	18.2		39.1	85.0	
	7.6	45.5		50.0	3.0		27.3	25.8	
Total	20	46	66	55	11	66	46	20	66
	30.3	69.7	100.0	83.3	16.7	100.0	69.7	30.3	100.0
	Chi Square		7.51	Chi Square		4.87	Chi Square		10.01
	df		1	df		1	df		1
	Phi		.37	Phi		.31	Phi		.42
	Significance		.006	Significance		.03	Significance		.002

Table 139

Interview Data Analyses: Stoichiometry - Problem 2
Proportional Reasoning Ability

Proportional Reasoning Ability	Use of Random Trial and Error			Comments About Solution			
	0	1	Total	0	1	2	Total
Low	20 64.5 38.5 30.3	11 35.5 78.6 16.7	31 47.0	11 35.5 31.4 16.7	20 64.5 69.0 30.3	0 0 0 0	31 47.0 (38.6)
High	32 91.4 61.5 48.5	3 8.6 21.4 4.5	35 53.0	24 68.6 68.6 36.4	9 25.7 31.0 13.6	2 5.7 100.0 3.0	35 53.0 (28.9)
Total	52 78.8	14 21.2	66 100.0	35 53.0	29 43.9	2 3.0	66 100.0

Chi Square	5.61
df	1
Phi	.33
Significance	.02

Mann-Whitney U	702
Wilcoxon Rank Sum W	1198
Z	2.34
Significance	.02

Table 140

Interview Data Analyses: Stoichiometry - Problem 3
Proportional Reasoning Ability

Proprotional Reasoning Ability	Systemmatic Approach 0	Systemmatic Approach 1	Systemmatic Approach Total	Algorithmic Reasoning Strategy 0	Algorithmic Reasoning Strategy 1	Algorithmic Reasoning Strategy Total
Low	21	10	31	31	0	31
	67.7	32.3	47.0	100.0	0	47.0
	61.8	31.3		55.4	0	
	31.8	15.2		47.0	0	
High	13	22	35	25	10	35
	37.1	62.9	53.0	71.4	28.6	53.0
	38.2	68.8		44.6	100.0	
	19.7	33.3		37.9	15.2	
Total	34	32	66	56	10	66
	51.5	48.5	100.0	84.8	15.2	100.0
	Chi Square	5.00		Chi Square	8.33	
	df	1		df	1	
	Phi	.30		Phi	.40	
	Significance	.03		Significance	.004	

Table 141

Interview Data Analyses: Stoichiometry - Problem 3
Proportional Reasoning Ability

Proportional Reasoning Ability	Comments About Solution			Structural Error - 3				
	0	1	Total	0	1	2	3	Total
Low	5[a] 16.1[b] 21.7[c] 7.6[d]	26 83.9 60.5 39.4	31 47.0 (39.7)[e]	22 71.0 57.9 33.3	0 0 0 0	4 12.9 40.0 6.1	5 16.1 71.4 7.6	31 47.0
High	18 51.4 78.3 27.3	17 48.6 39.5 25.8	35 53.0 (28.0)	16 45.7 42.1 24.2	1 31.4 100.0 16.7	6 17.1 60.0 9.1	2 5.7 28.6 3.0	35 53.0
Total	23 34.8	43 65.2	66 100.0	38 57.6	11 16.7	10 15.2	7 10.6	66 100.0
	Mann-Whitney U		734		Chi Square		13.44	
	Wilcoxon Rank Sum W		1230		df		3	
	Z		2.98		V		.45[f]	
	Significance		.003		Significance		.004	

[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[e] Mean rank
[f] Cramer's V

Table 142

Interview Data Analyses: Stoichiometry - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Systemmatic Approach					Algorithmic Reasoning Strategy				
	0	1	2	3	Total	0	1	2	3	Total
Low	12	4	6	9	31	28	1	2	0	31
	38.7	12.9	19.4	29.0	47.0	90.3	3.2	6.5	0	47.0
	80.0	50.0	50.0	29.0	(26.1)	62.2	33.3	25.0	0	(25.7)
	18.2	6.1	9.1	13.6		42.4	1.5	3.0	0	
High	3	4	6	22	35	17	2	6	10	35
	8.6	11.4	17.1	62.9	53.0	48.6	5.7	17.1	28.6	53.0
	20.0	50.0	50.0	71.0	(40.0)	37.8	66.7	75.0	100.0	(40.4)
	4.5	6.1	9.1	33.3		25.8	3.0	9.1	15.2	
Total	15	8	12	31	66	45	3	8	10	66
	22.7	12.1	18.2	47.0	100.0	68.2	4.5	12.1	15.2	100.0

Mann-Whitney U	314	Mann-Whitney U	300
Wilcoxon Rank Sum W	810	Wilcoxon Rank Sum W	796
Z	-3.13	Z	-3.78
Significance	.002	Significance	.0002

Table 143

Interview Data Analyses: Stoichiometry - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Use of Random Trial and Error					Comments About Solution					
	0	1	2	3	Total	0	1	2	3	4	Total
Low	17	5	4	5	31	0	9	5	16	1	31
	54.8	16.1	12.9	16.1	47.0	0	29.0	16.1	51.6	3.2	47.0
	39.5	45.5	66.7	83.3	(37.6)	0	45.0	41.7	76.2	100.0	(43.3)
	25.8	7.6	6.1	7.6		0	13.6	7.6	24.2	1.5	
High	26	6	2	1	35	12	11	7	5	0	35
	74.3	17.1	5.7	2.9	53.0	34.3	31.4	20.0	14.3	0	53.0
	60.5	54.5	33.3	16.7	(29.8)	100.0	55.0	58.3	23.8	0	(24.9)
	39.4	9.1	3.0	1.5		18.2	16.7	10.6	7.6	0	
Total	43	11	6	6	66	12	20	12	21	1	66
	65.2	16.7	9.1	9.1	100.0	18.2	30.3	18.2	31.8	1.5	100.0

Mann-Whitney U	670	Mann-Whitney U	845
Wilcoxon Rank Sum W	1166	Wilcoxon Rank Sum W	1341
Z	1.94	Z	4.03
Significance	.05	Significance	.0001

Table 144

Interview Data Analyses: Stoichiometry - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Problems Correct 0	1	2	3	Total	Questions Correct 2	3	4	Total
Low	22	9	0	0	31	5	12	14	31
	71.0	29.0	0	0	47.0	16.1	38.7	45.2	47.0
	55.0	56.3	0	0	(28.6)	50.0	75.0	35.0	(29.0)
	33.3	13.6	0	0		7.6	18.2	21.2	
High	18	7	6	4	35	5	4	26	35
	51.4	20.0	17.1	11.4	53.0	14.3	11.4	74.3	53.0
	45.0	43.8	100.0	100.0	(37.8)	50.0	25.0	65.0	(37.4)
	27.3	10.6	9.1	6.1		7.6	6.1	39.4	
Total	40	16	6	4	66	10	16	40	66
	60.6	24.2	9.1	6.1	100.0	15.2	24.2	60.6	100.0

Mann-Whitney U	391	Mann-Whitney U	404
Wilcoxon Rank Sum W	887	Wilcoxon Rank Sum W	900
Z	-2.22	Z	-2.03
Significance	.03	Significance	.04

Table 145

Interview Data Analyses: Molarity - Problem 1
Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Reasoning Strategy			Use of Random Trial and Error		
	0	1	Total	0	1	Total
	28	1	29	22	7	29
	96.6	3.4	45.3	75.9	24.1	45.3
Low	63.6	5.0		39.3	87.5	
	43.8	1.6		34.4	10.9	
	16	19	35	34	1	35
	45.7	54.3	54.7	97.1	2.9	54.7
High	36.4	95.0		60.7	12.5	
	25.0	29.7		53.1	1.6	
Total	44	20	64	56	8	64
	68.8	31.3	100.0	87.5	12.5	100.0
	Chi Square		16.79	Chi Square		4.77
	df		1	df		1
	Phi		.54	Phi		.32
	Significance		<.0001	Significance		.03

Table 146

Interview Data Analyses: Molarity - Problem 1
Proportional Reasoning Ability

Proportional Reasoning Ability	Structural Error 1 0	1	3	4	6	7	8	9	Total
Low	3 10.3 42.9 4.7	7 24.1 87.5 10.9	4 13.8 100.0 6.3	1 3.4 100.0 1.6	1 3.4 50.0 1.6	0 0 0 0	5 17.2 62.5 7.8	8 27.6 25.8 12.5	29 45.3
High	4 11.4 57.1 6.3	1 2.9 12.5 1.6	0 0 0 0	0 0 0 0	1 2.9 50.0 1.6	3 8.6 100.0 4.7	3 8.6 37.5 4.7	23 65.7 74.2 35.9	35 54.7
Total	7 10.9	8 12.5	4 6.3	1 1.6	2 3.1	3 4.7	8 12.5	31 48.4	64 100.0

Chi Square	20.01
df	7
V	.56
Significance	.006

Table 147

Interview Data Analyses: Molarity - Problem 1
Proportional Reasoning Ability

Proportional Reasoning Ability	Structural Error - 2							
	0	1	2	6	7	8	9	Total
	6	0	5	12	2	3	1	29
	20.7	0	17.2	41.4	6.9	10.3	3.4	45.3
Low	60.0	0	71.4	85.7	50.0	11.5	100.0	
	9.4	0	7.8	18.8	3.1	4.7	1.6	
	4	2	2	2	2	23	0	35
	11.4	5.7	5.7	5.7	5.7	65.7	0	54.7
High	40.0	100.0	28.6	14.3	50.0	88.5	0	
	6.3	3.1	3.1	3.1	3.1	35.9	0	
Total	10	2	7	14	4	26	1	64
	15.6	3.1	10.9	21.9	6.3	40.6	1.6	100.0

Chi Square	26.89
df	6
V	.65
Significance	.0002

Table 148

Interview Data Analyses: Molarity - Problem 2 Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Reasoning Strategy 0	1	Total
	27	2	29
	93.1	6.9	45.3
Low	56.3	12.5	
	42.2	3.1	
	21	14	35
	60.0	40.0	54.7
High	43.8	87.5	
	32.8	21.9	
Total	48	16	64
	75.0	25.0	100.0

Chi Square	7.59
df	1
Phi	.38
Significance	.006

Table 149

Interview Data Analyses: Molarity - Problem 3
Proportional Reasoning Ability

Proportional Reasoning Ability	Rereading/Stating Problem				Algorithmic Reasoning Strategy			Comments About Solution		
	0	1	2	Total	0	1	Total	0	1	Total
Low	14	14	1	29	26	3	29	10	19	29
	48.3	48.3	3.4	45.3	89.7	10.3	45.3	34.5	65.5	45.3
	58.3	42.4	14.3	(27.9)	54.2	18.8		32.3	57.6	(37.0)
	21.9	21.9	1.6		40.6	4.7		15.6	29.7	
High	10	19	6	35	22	13	35	21	14	35
	28.6	54.3	17.1	54.7	62.9	37.1	54.7	60.0	40.0	54.7
	41.7	57.6	85.7	(36.3)	45.8	81.3		67.7	42.4	(28.8)
	15.6	29.7	9.4		34.4	20.3		32.8	21.9	
Total	24	33	7	64	48	16	64	31	33	64
	37.5	51.6	10.9	100.0	75.0	25.0	100.0	48.4	51.6	100.0

Mann-Whitney U	375	Chi Square	4.73	Mann-Whitney U	637
Wilcoxon Rank Sum W	810	df	1	Wilcoxon Rank Sum W	1072
Z	-1.99	Phi	.31	Z	2.02
Significance	.05	Significance	.03	Significance	.04

Table 150

Interview Data Analyses: Molarity - Problem 3
Proportional Reasoning Ability

Proportional	Structural Error - 2						Structural Error - 3				
Reasoning Ability	0	1	2	3	4	Total	0	1	2	3	Total
Low	12	2	4	7	4	29	16	0	7	6	29
	41.4	6.9	13.8	24.1	13.8	45.3	55.2	0	24.1	20.7	45.3
	66.7	15.4	26.7	53.8	80.0		45.7	0	87.5	33.3	
	18.8	3.1	6.3	10.9	6.3		25.0	0	10.9	9.4	
High	6	11	11	6	1	35	19	3	1	12	35
	17.1	31.4	31.4	17.1	2.9	54.7	54.3	8.6	2.9	34.3	54.7
	33.3	84.6	73.3	46.2	20.0		54.3	100.0	12.5	66.7	
	9.4	17.2	17.2	9.4	1.6		29.7	4.7	1.6	18.8	
Total	18	13	15	13	5	64	35	3	8	18	64
	28.1	20.3	23.4	20.3	7.8	100.0	54.7	4.7	12.5	28.1	100.0
		Chi Square		12.93				Chi Square		9.28	
		df		4				df		3	
		V		.45				V		.38	
		Significance		.01				Significance		.03	

Table 161

Interview Data Analyses: Molarity - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Nonsystemmatic Approach 0	1	2	3	Total	Algorithmic Strategy Only 0	1	2	3	Total
Low	17	7	3	2	29	6	7	11	5	29
	58.6	24.1	10.3	6.9	45.3	20.7	24.1	37.9	17.2	45.3
	37.8	58.3	60.0	100.0	(36.5)	33.3	35.0	55.0	83.3	(37.8)
	26.6	10.9	4.7	3.1		9.4	10.9	17.2	7.8	
High	28	5	2	0	35	12	13	9	1	35
	80.0	14.3	5.7	0	54.7	34.3	37.1	25.7	2.9	54.7
	62.2	41.7	40.0	0	(29.2)	66.7	65.0	45.0	16.7	(28.1)
	43.8	7.8	3.1	0		18.8	20.3	14.1	1.6	
Total	45	12	5	2	64	18	20	20	6	64
	70.3	18.8	7.8	3.1	100.0	28.1	31.3	31.3	9.4	100.0

Mann-Whitney U	623	Mann-Whitney U	662
Wilcoxon Rank Sum W	1058	Wilcoxon Rank Sum W	1097
Z	1.95	Z	2.18
Significance	.05	Significance	.03

Table 152

Interview Data Analyses: Molarity - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Algorithmic Reasoning Strategy					Use of Random Trial and Error				
	0	1	2	3	Total	0	1	2	3	Total
Low	25	3	0	1	29	16	8	3	2	29
	86.2	10.3	0	3.4	45.3	55.2	27.6	10.3	6.9	45.3
	67.6	27.3	0	11.1	(22.9)	36.4	57.1	75.0	100.0	(37.3)
	39.1	4.7	0	1.6		25.0	12.5	4.7	3.1	
High	12	8	7	8	35	28	6	1	0	35
	34.3	22.9	20.0	22.9	54.7	80.0	17.1	2.9	0	54.7
	32.4	72.7	100.0	88.9	(40.5)	63.6	42.9	25.0	0	(28.6)
	18.8	12.5	10.9	12.5		43.8	9.4	1.6	0	
Total	37	11	7	9	64	44	14	4	2	64
	57.8	17.2	10.9	14.1	100.0	68.8	21.9	6.3	3.1	100.0

Mann-Whitney U	229	Mann-Whitney U	645
Wilcoxon Rank Sum W	664	Wilcoxon Rank Sum W	1080
Z	-4.20	Z	2.28
Significance	<.0001	Significance	.02

Table 153

Interview Data Analyses: Molarity - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Disregards Information Given				Comments About Solution				
	0	1	2	Total	0	1	2	3	Total
Low	20	7	2	29	5	11	10	3	29
	69.0	24.1	6.9	45.3	17.2	37.9	34.5	10.3	45.3
	38.5	70.0	100.0	(36.5)	27.8	40.7	71.4	60.0	(38.3)
	31.3	10.9	3.1		7.8	17.2	15.6	4.7	
High	32	3	0	35	13	16	4	2	35
	91.4	8.6	0	54.7	37.1	45.7	11.4	5.7	54.7
	61.5	30.0	0	(29.2)	72.2	59.3	28.6	40.0	(27.7)
	50.0	4.7	0		20.3	25.0	6.3	3.1	
Total	52	10	2	64	18	27	14	5	64
	81.3	15.6	3.1	100.0	28.1	42.2	21.9	7.8	100.0

Mann-Whitney U	624	Mann-Whitney U	675
Wilcoxon Rank Sum W	1059	Wilcoxon Rank Sum W	1110
Z	2.33	Z	2.40
Significance	.02	Significance	.02

Table 154

Interview Data Analyses: Molarity - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Problems Correct					Questions Correct				
	0	1	2	3	Total	0	1	2	3	Total
Low	26	2	1	0	29	5	17	5	2	29
	89.7	6.9	3.4	0	45.3	17.2	58.6	17.2	6.9	45.3
	66.7	13.3	12.5	0	(23.2)	83.3	68.0	22.7	18.2	(23.1)
	40.6	3.1	1.6	0		7.8	26.6	7.8	3.1	
High	13	13	7	2	35	1	8	17	9	35
	37.1	37.1	20.0	5.7	54.7	2.9	22.9	48.6	25.7	54.7
	33.3	86.7	87.5	100.0	(40.2)	16.7	32.0	77.3	81.8	(40.3)
	20.3	20.3	10.9	3.1		1.6	12.5	26.6	14.1	
Total	39	15	8	2	64	6	25	22	11	64
	60.9	23.4	12.5	3.1	100.0	9.4	39.1	34.4	17.2	100.0

Problems Correct	
Mann-Whitney U	237
Wilcoxon Rank Sum W	672
Z	-4.18
Significance	<.0001

Questions Correct	
Mann-Whitney U	236
Wilcoxon Rank Sum W	671
Z	-3.87
Significance	.0001

Table 155

Interview Data Analyses: Molarity - Total Proportional Reasoning Ability

Proportional Reasoning Ability	Questions Correct Without Prompting						
	0	1	2	3	4	5	Total
Low	3	6	13	5	2	0	29
	10.3	20.7	44.8	17.2	6.9	0	45.3
	100.0	85.7	52.0	31.3	25.0	0	(23.3)
	4.7	9.4	20.3	7.8	3.1	0	
High	0	1	12	11	6	5	35
	0	2.9	34.3	31.4	17.1	14.3	54.7
	0	14.3	48.0	68.8	75.0	100.0	(40.1)
	0	1.6	18.8	17.2	9.4	7.8	
Total	3	7	25	16	8	5	64
	4.7	10.9	39.1	25.0	12.5	7.8	100.0

Mann-Whitney U	240
Wilcoxon Rank Sum W	675
Z	-3.75
Significance	.0002

all analyses (Tables 136, 138, 140, 142), and molarity, all analyses (Tables 145, 148, 149, 152). Students with high proportional reasoning ability used algorithmic reasoning stratgies more frequently than low proportional reasoning students in solving problems.

Random trial and error. Moles, total (Table 127), stoichiometry, problem 2, total (Tables 139, 143), and molarity, problem 1, total (Tables 145, 152). Low proportional reasoning students made a greater use of this strategy.

Disregards what is given in problem. Molarity, total (Table 153). Low proportional reasoning students more frequently didthis.

Comments about solution. Moles, problems 1, 3, total (Tables 123, 125, 128),gas laws, problem 1,(Table 131), stoichiometry, all problems, total (Tables 136, 139, 141, 143), and molarity, problem 3, total (Tables 149, 153). Low proportional reasoning students made comments about the solution more frequently.

Problems correct. Analyzed only for totals and significant for moles (Table 128), stoichiometry (Table 144), and molarity (Table 154). High proportional reasoning students got the problems correct more frequently.

Questions correct. Analyzed only for totals and significant for moles (Table129), stoichiometry (Table 144), and molarity (Table 154). High proportional reasoning students got more questions correct.

Questions without prompting correct. Analyzed only for totals and significant for moles (Table 130), and molarity (Table 155). High proportional reasoning students answered questions correctly without prompting more frequently.

Structural errors. Structural errors are analyzed according to each chemistry unit.

1. Stoichiometry 1 - 1, Table 137. Students with high proportional reasoning ability more frequently remembered to balance the equation

in solving a simple stoichiometry problem.

2. Stoichiometry 3 - 3, Table 141. A greater number of high proportional reasoning students attempted to solve the problems than low proportional reasoning students.

3. Molarity 1 - 1, Table 146. A greater number of high proportional reasoning students calculated and used molecular weights correctly in solving a simple molarity problem than low proportional reasoning students.

4. Molarity 1 - 2, Table 147. A greater number of high proportional reasoning students used the definition of molarity and made mL to L changes correctly than low proportional reasoning ability students.

5. Molarity 3 - 2, Table 150. A greater proportion of high proportional reasoning students realize that an equation must be used and use the balanced equation correctly when solving stoichiometry - molarity problems than low proportional reasoning students.

6. Molarity 3 - 3, Table 150. More high proprotional reasoning students used the definition of molarity correctly in solving a complex molarity problem than low proportional reasoning students.

Hypothesis 3

There are no significant differences in chemistry problem solving strategies used by students considered successful problem solvers versus unsuccessful ones.

Three different methods were used to judge whether students were considered successful or unsuccessful. Method one was based on dividing the group of students interviewed for each part approximately in half according to their scores on the delayed posttest. Method two divided each group into approximately three equal parts based on this same test. Method three divided the group into two parts based on students' combined delayed and immediate posttest scores. Because all three methods produced similar results, only method two is presented here. Table 156 lists the characteristics of the groups, Table 157 gives a summary of the findings and Tables 158-192 present more detail for analyses that produced significant findings.

Reading/organizing. Moles, problem 1, total (Tables 158, 164). Results are not definitive. Students of middle and high success tended to read and organize more. No significant differences in three other units.

Mneumonics. Moles, problem 1, 2, total (Tables 158, 160,165) and stoichiometry, problem 1 (Table 167). Successful students used mneumonic notation more frequently.

Systemmatic production. Moles, all problems (Tables 158, 160, 162, 165), gas laws, total (Table 174), and stoichiometry, problem 1, 2, total (Tables 176, 179, 183). Successful students used systemmatic approaches.

Arithmetic approach. Moles, total (Table 166), stoichiometry, problems 1, 2, total (Tables 176, 179,183), and molarity, problem 3 (Table 189). Successful students used an arithmetic approach.

Nonsystemmatic approach. Moles, problems 1, 3, total (Tables 159, 162, 166), stoichiometry, problems 1, 2, total (Tables 177, 179, 184), and molarity, problem 3, total (Tables 189, 191). In general, unsuccessful students were nonsystemmatic in their approach to problem solving.

No answer given. Moles, problems 2, 3, total (Tables 160, 162, 167), and stoichiometry, problem 1 (Table 177). This was more prevalent among unsuccessful students.

Algorithmic/reasoning strategy. Moles, all problems (Tables 159, 161, 163, 167), gas laws, all problems (Tables 171, 172, 173, 174), stoichiometry, all problems (Tables 178, 181, 182, 184), and molarity, problem 3 (Table 189). This strategy was used by successful students.

Random trial and error. Moles, problem 3, total, (Tables 163,168), and molarity, problem 2, total (Tables 188, 191). This strategy was used more by

Table 156

Distribution of Students According

to Scores on Delayed Posttest

Unit	Low			Middle			High		
	Range	X	N	Range	X	N	Range	X	N
Moles	1-5	3.8	20	6-8	7.4	22	9-10	9.6	32
Gas Laws	1-5	3.8	19	6-8	7.0	25	9-10	9.8	20
Stoichiometry	1-5	3.1	21	6-8	7.2	24	9-10	9.4	21
Molarity	2-5	3.9	15	6-7	6.7	24	8-10	8.8	16

Table 157

Summary of Significant Findings: High, Middle or Low Success on Tests

Protocol Categories	Moles				Gas Laws				Stoichiometry				Molarity			
	P1[a]	P2[b]	P3[c]	T[d]	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Reading/Organizing	11.04[e] .004[f]			7.17 .03												
Rereads or Stating[g]																
Mneumonics	9.83 .007	6.19 .05		10.47 .005					5.85 .05							
Production																
Systemmatic	11.21 .004	12.15 .002	10.57 .005	17.25 .0002				7.57 .02	12.78 .002	9.83 .007		9.44 .009				
Approach Taught																
Arithmetic				7.12 .03					7.62 .02	6.46 .04		6.95 .03			6.92 .03	
Nonsystemmatic	6.20 .05		9.44 .009	12.80 .002					6.64 .04	6.99 .03		6.30 .04			6.08 .05	6.61 .04
No Answer		11.42 .003	6.20 .05	7.82 .02					6.77 .03							
Strategy																
Algorithmic																
Alg/Reasoning	9.06 .01	15.04 .0005	16.84 .0002	16.09 .0003	8.17 .02	9.58 .008	18.66 .0001	15.37 .0005	16.49 .0003	19.30 .0001	12.61 .002	21.55 <.0001			11.28 .004	
Random T & E			9.44 .009	12.10 .002										6.11 .05		6.44 .04
Structural Error																
Misinterprets																
Disregards given																
Disregards gen																
Misapplies																
Not generate																

Table 157 (continued)

Summary of Significant Findings: High, Middle or Low Success on Tests

Protocol Categories	Moles				Gas Laws				Stoichiometry				Molarity			
	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Evaluation																
*Comments about Solution	11.43 .003	8.10 .02	10.31 .006	16.32 .0003					15.49 .004	8.35 .02		14.13 .0009				
*Executive Errors						6.10 .05					11.42 .003	10.78 .005				
*Problems Correct	X[i]	X	X	15.44 .0004	X	X	X	8.14 .02	X	X	X	12.43 .002	X	X	X	6.46 .04
*Questions Correct	X	X	X	20.68 < .0001	X	X	X		X	X	X	9.11 .01	X	X	X	
*Question w/o Prompting	X	X	X	22.11 < .0001	X	X	X		X	X	X	6.19 .05	X	X	X	
Structural Errors																
Section[h] 1 - 1	X	X	X	X		X	X	X		X	X	X		X	X	X
Section 1 - 2	X	X	X	X		X	X	X	18.45 .005	X	X	X		X	X	X
Section 2 - 1	X	X	X	X	X		X	X	X		X	X	X		X	X
Section 2 - 2	X	X	X	X	X		X	X	X	12.68 .05	X	X	X		X	X
Section 3 - 1	X	X	X	X	X	X		X	X	X		X	X	X		X
Section 3 - 2	X	X	X	X	X	X	28.53 .01	X	X	X		X	X	X	22.00 .005	X
Section 3 - 3	X	X	X	X	X	X		X	X	X	13.54 .04	X	X	X	18.07 .006	X

*Category sum

[a] Problem 1

[b] Problem 2

[c] Problem 3

[d] Sum of Problems 1, 2 & 3

[e] Statistic

[f] Probability level

[g] Sum of rereads and restates subcategories

[h] Section on supplementary coding sheet

[i] Not meaningful

Table 158

Interview Data Analyses: Moles - Problem 1
High, Middle or Low Success on Tests

Success on Tests	Reading/Organizing Skills 0	1	2	3	Total	Use of Mneumonics Notation 0	1	Total	Systemmatic Approach 0	1	Total
Low	13[a]	5	2	0	20	17	3	20	8	12	20
	65.0[b]	25.0	10.0	0	27.0	85.0	15.0	27.0	40.0	60.0	27.0
	44.8[c]	16.1	16.7	0	(27.6)[e]	39.5	9.7	(27.5)	57.1	20.0	
	17.6[d]	6.8	2.7	0		23.0	4.1		10.8	16.2	
Middle	4	10	6	2	22	13	9	22	5	17	22
	18.2	45.5	27.3	9.1	29.7	59.1	40.9	29.7	22.7	77.3	29.7
	13.8	32.3	50.0	100.0	(48.0)	30.2	29.0	(37.1)	35.7	28.3	
	5.4	13.5	8.1	2.7		17.6	12.2		6.8	23.0	
High	12	16	4	0	32	13	19	32	1	31	32
	37.5	50.0	12.5	0	43.2	40.6	59.4	43.2	3.1	96.9	43.2
	41.4	51.6	33.3	0	(36.4)	30.2	61.3	(44.0)	7.1	51.7	
	16.2	21.6	5.4	0		17.6	25.7		1.4	41.9	
Total	29	31	12	2	74	43	31	74	14	60	74
	39.2	41.9	16.2	2.7	100.0	58.1	41.9	100.0	18.9	81.1	100.0
	KW Chi Square		11.04			KW Chi Square		9.83	Chi Square		11.21
	df		6			df		2	df		2
	Significance		.004			Significance		.007	V		.39[f]
									Significance		.004

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[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[e] Mean rank
[f] Cramer's V

Table 159

Interview Data Analyses: Moles - Problem 1
High, Middle or Low Success on Tests

Success on Tests	Nonsystemmatic Approach			Algorithmic Reasoning Strategy			Comments About Solution				
	0	1	Total	0	1	Total	0	1	2	3	Total
	15	5	20	17	3	20	10	7	3	0	20
	75.0	25.0	27.0	85.0	15.0	27.0	50.0	35.0	15.0	0	27.0
Low	22.7	62.5		29.3	18.8		18.9	41.2	100.0	0	(46.0)
	20.3	6.8		23.0	4.1		13.5	9.5	4.1	0	
	20	2	22	21	1	22	14	7	0	1	22
	90.9	9.1	29.7	95.5	4.5	29.7	63.6	31.8	0	4.5	29.7
Middle	30.3	25.0		36.2	6.3		26.4	41.2	0	100.0	(40.3)
	27.0	2.7		28.4	1.4		18.9	9.5	0	1.4	
	31	1	32	20	12	32	29	3	0	0	32
	96.9	3.1	43.2	62.5	37.5	43.2	90.6	9.4	0	0	43.2
	47.0	12.5		34.5	75.0		54.7	17.6	0	0	(30.3)
High	41.9	1.4		27.0	16.2		39.2	4.1	0	0	
Total	66	8	74	58	16	74	53	17	3	1	74
	89.2	10.8	100.0	78.4	21.6	100.0	71.6	23.0	4.1	4.1	100.0
	Chi Square		6.20	Chi Square		9.06		KW Chi Square			11.43
	df		2	df		2		df			6
	V		.29	V		.35		Significance			.003
	Significance		.05	Significance		.01					

Table 160

Interview Data Analyses: Moles - Problem 2
High, Middle or Low Success on Tests

Success on Tests	Use of Mneumonic Notation			Systemmatic Approach			No Answer Given		
	0	1	Total	0	1	Total	0	1	Total
	14	6	20	9	11	20	16	4	20
	70.0	30.0	27.0	45.0	55.0	27.0	80.0	20.0	27.0
Low	38.9	15.8	(29.6)	64.3	18.3		22.9	100.0	
	18.9	8.1		12.2	14.9		21.6	5.4	
	11	11	22	2	20	22	22	0	22
	50.0	50.0	29.7	9.1	90.9	29.7	100.0	0	29.7
Middle	30.6	28.9	(37.0)	14.3	33.3		31.4	0	
	14.9	14.9		2.7	27.0		29.7	0	
	11	21	32	3	29	32	32	0	32
	34.4	65.6	43.2	9.4	90.6	43.2	100.0	0	43.2
High	30.6	55.3	(42.8)	21.4	48.3		45.7	0	
	14.9	28.4		4.1	39.2		43.2	0	
Total	36	38	74	14	60	74	70	4	74
	48.6	51.4	100.0	18.9	81.1	100.0	94.6	5.4	100.0
	KW Chi Square		6.19	Chi Square		12.15	Chi Square		11.42
	df		2	df		2	df		2
	Significance		.05	V		.40	V		.39
				Significance		.002	Significance		.003

Table 161

Interview Data Analyses: Moles - Problem 2
High, Middle or Low Success on Tests

Success on Tests	Algorithmic Reasoning Strategy 0	1	Total	Comments About Solution 0	1	2	Total
Low	19	1	20	9	10	1	20
	95.0	5.0	27.0	45.0	50.0	5.0	27.0
	38.8	4.0		18.0	50.0	25.0	(45.3)
	25.7	1.4		12.2	13.5	1.4	
Middle	16	6	22	14	6	2	22
	72.7	27.3	29.7	63.6	27.3	9.1	29.7
	32.7	24.0		28.0	30.0	50.0	(39.3)
	21.6	8.1		18.9	8.1	2.7	
High	14	18	32	27	4	1	32
	43.8	56.3	43.2	84.4	12.5	3.1	43.2
	28.6	72.0		54.0	20.0	25.0	(31.3)
	18.9	24.3		36.5	5.4	1.4	
Total	49	25	74	50	20	4	74
	66.2	33.8	100.0	67.6	27.0	5.4	100.0

Chi Square	15.04
df	2
V	.45
Significance	.0005

KW Chi Square	8.10
df	4
Significance	.02

Table 162

Interview Data Analyses: Moles - Problem 3
High, Middle or Low Success on Tests

Success on Tests	Systemmatic Approach			Nonsystemmatic Approach			No Answer Given		
	0	1	Total	0	1	Total	0	1	Total
Low	14	6	20	11	9	20	15	5	20
	70.0	30.0	27.0	55.0	45.0	27.0	75.0	25.0	27.0
	46.7	13.6		19.0	56.3		22.7	62.5	
	18.9	8.1		14.9	12.2		20.3	6.8	
Middle	8	14	22	18	4	22	20	2	22
	36.4	63.6	29.7	81.8	18.2	29.7	90.9	9.1	29.7
	26.7	31.8		31.0	25.0		30.3	25.0	
	10.8	18.9		24.3	5.4		27.0	2.7	
High	8	24	32	29	3	32	31	1	32
	25.0	75.0	43.2	90.6	9.4	43.2	96.9	3.1	43.2
	26.7	54.5		50.0	18.8		47.0	12.5	
	10.8	32.4		39.2	4.1		41.9	1.4	
Total	30	44	74	58	16	74	66	8	74
	40.5	59.5	100.0	78.4	21.6	100.0	89.2	10.8	100.0
	Chi Square		10.57	Chi Square		9.44	Chi Square		6.20
	df		2	df		2	df		2
	V		.38	V		.36	V		.29
	Significance		.005	Significance		.009	Significance		.05

Table 163

Interview Data Analyses: Moles - Problem 3
High, Middle or Low Success on Tests

Success on Tests	Algorithmic Reasoning Strategy 0	1	Total	Use of Random Trial and Error 0	1	Total	Comments About Solution 0	1	2	Total
Low	20	0	20	11	9	20	6	13	1	20
	100.0	0	27.0	55.0	45.0	27.0	30.0	65.0	5.0	27.0
	37.0	0		19.0	56.3		14.0	44.8	50.0	(48.0)
	27.0	0		14.9	12.2		8.1	17.6	1.4	
Middle	18	4	22	18	4	22	13	8	1	22
	81.8	18.2	29.7	81.8	18.2	29.7	59.1	36.4	4.5	29.7
	33.3	20.0		31.0	25.0		30.2	27.6	50.0	(37.4)
	24.3	5.4		24.3	5.4		17.6	10.8	1.4	
High	16	16	32	29	3	32	24	8	0	32
	50.0	50.0	43.2	90.6	9.4	43.2	75.0	25.0	0	43.2
	29.6	80.0		50.0	18.8		55.8	27.6	0	(31.0)
	21.6	21.6		39.2	4.1		32.4	10.8	0	
Total	54	20	74	58	16	74	43	29	2	74
	73.0	27.0	100.0	78.4	21.6	100.0	58.1	39.2	2.7	100.0

Algorithmic Reasoning Strategy		Use of Random Trial and Error		Comments About Solution	
Chi Square	16.84	Chi Square	9.44	KW Chi Square	10.31
df	2	df	2	df	4
V	.48	V	.36	Significance	.006
Significance	.0002	Significance	.009		

Table 164

Interview Data Analyses: Moles - Total
High, Middle or Low Success on Tests

Success on Tests	Reading/Organizing Skills							
	0	1	2	3	4	5	7	Total
Low	5	5	4	1	4	1	0	20
	25.0	25.0	20.0	5.0	20.0	5.0	0	27.0
	50.0	62.5	23.5	5.9	33.3	12.5	0	(27.7)
	6.8	6.8	5.4	1.4	5.4	1.4	0	
Middle	0	2	6	4	6	4	0	22
	0	9.1	27.3	18.2	27.3	18.2	0	29.7
	0	25.0	35.3	23.5	50.0	50.0	0	(45.1)
	0	2.7	8.1	5.4	8.1	5.4	0	
High	5	1	7	12	2	3	2	32
	15.6	3.1	21.9	37.5	6.3	9.4	6.3	43.2
	50.0	12.5	41.2	70.6	16.7	37.5	100.0	(38.4)
	6.8	1.4	9.5	16.2	2.7	4.1	2.7	
Total	10	8	17	17	12	8	2	74
	13.5	10.8	23.0	23.0	16.2	10.8	2.7	100.0

KW Chi Square	7.17
df	12
Significance	.03

Table 165

Interview Data Analyses: Moles - Total
High, Middle or Low Success on Tests

Success on Tests	Use of Mneumonic Notation 0	1	2	3	Total	Systemmatic Approach 0	1	2	3	Total
	12	4	2	2	20	5	5	6	4	20
	60.0	20.0	10.0	10.0	27.0	25.0	25.0	30.0	20.0	27.0
Low	48.0	26.7	14.3	10.0	(25.6)	71.4	62.5	28.6	10.5	(22.8)
	16.2	5.4	2.7	2.7		6.8	6.8	8.1	5.4	
	7	5	4	6	22	1	2	8	11	22
	31.8	22.7	18.2	27.3	29.7	4.5	9.1	36.4	50.0	29.7
Middle	28.0	33.3	28.6	30.0	(37.9)	14.3	25.0	38.1	28.9	(38.4)
	9.5	6.8	5.4	8.1		1.4	2.7	10.8	14.9	
	6	6	8	12	32	1	1	7	23	32
	18.8	18.8	25.0	37.5	43.2	3.1	3.1	21.9	71.9	43.2
High	24.0	40.0	57.1	60.0	(44.7)	14.3	12.5	33.3	60.5	(46.1)
	8.1	8.1	10.8	16.2		1.4	1.4	9.5	31.1	
Total	25	15	14	20	74	7	8	21	38	74
	33.8	20.3	18.9	27.0	100.0	9.5	10.8	28.4	51.4	100.0

	Use of Mneumonic Notation		Systemmatic Approach	
	KW Chi Square	10.47	KW Chi Square	17.25
	df	6	df	6
	Significance	.005	Significance	.0002

Table 166

Interview Data Analyses: Moles - Total
High, Middle or Low Success on Tests

Success on Tests	Arithmetic Approach					Nonsystemmatic Approach				
	0	1	2	3	Total	0	1	2	3	Total
	7	6	5	2	20	8	7	3	2	20
	35.0	30.0	25.0	10.0	27.0	40.0	35.0	15.0	10.0	27.0
Low	30.4	60.0	27.8	8.7	(29.7)	15.4	53.8	50.0	66.7	(48.8)
	9.5	8.1	6.8	2.7		10.8	9.5	4.1	2.7	
	9	2	5	6	22	16	4	2	0	22
	40.9	9.1	22.7	27.3	29.7	72.7	18.2	9.1	0	29.7
Middle	39.1	20.0	27.8	26.1	(34.3)	30.8	30.8	33.3	0	(36.2)
	12.2	2.7	6.8	8.1		21.6	5.4	2.7	0	
	7	2	8	15	32	28	2	1	1	32
	21.9	6.3	25.0	46.9	43.2	87.5	6.3	3.1	3.1	43.2
High	30.4	20.0	44.4	65.2	(44.6)	53.8	15.4	16.7	33.3	(31.3)
	9.5	2.7	10.8	20.3		37.8	2.7	1.4	1.4	
Total	23	10	18	23	74	52	13	6	3	74
	31.1	13.5	24.3	31.1	100.0	70.3	17.6	8.1	4.1	100.0

Arithmetic Approach		Nonsystemmatic Approach	
KW Chi Square	7.12	KW Chi Square	12.80
df	6	df	6
Significance	.03	Significance	.002

Table 167

Interview Data Analyses: Moles - Total
High, Middle or Low Success on Tests

Success on Tests	No Answer Given					Algorithmic Reasoning Strategy				
	0	1	2	3	Total	0	1	2	3	Total
Low	14	2	2	2	20	17	2	1	0	20
	70.0	10.0	10.0	10.0	27.0	85.0	10.0	5.0	0	27.0
	22.2	28.6	100.0	100.0	(43.6)	37.8	25.0	10.0	0	(27.4)
	18.9	2.7	2.7	2.7		23.0	2.7	1.4	0	
Middle	18	4	0	0	22	16	2	3	1	22
	81.8	18.2	0	0	29.7	72.7	9.1	13.6	4.5	29.7
	28.6	57.1	0	0	(38.4)	35.6	25.0	30.0	9.1	(32.3)
	24.3	5.4	0	0		21.6	2.7	4.1	1.4	
High	31	1	0	0	32	12	4	6	10	32
	96.9	3.1	0	0	43.2	37.5	12.5	18.8	31.3	43.2
	49.2	14.3	0	0	(33.1)	26.7	50.0	60.0	90.9	(47.3)
	41.9	1.4	0	0		16.2	5.4	8.1	13.5	
Total	63	7	2	2	74	45	8	10	11	74
	85.1	9.5	2.7	2.7	100.0	60.8	10.8	13.5	14.9	100.0

KW Chi Square	7.82	KW Chi Square	16.09
df	6	df	6
Significance	.02	Significance	.0003

Table 168

Interview Data Analyses: Moles - Total
High, Middle or Low Success on Tests

Success on Tests	Use of Random Trial and Error					Comments About Solution						
	0	1	2	3	Total	0	1	2	3	4	5	Total
Low	8	7	3	2	20	4	3	4	7	2	0	20
	40.0	35.0	15.0	10.0	27.0	20.0	15.0	20.0	35.0	10.0	0	27.0
	15.7	50.0	60.0	50.0	(48.3)	12.9	15.8	50.0	53.8	100.0	0	(50.3)
	10.8	9.5	4.1	2.7		5.4	4.1	5.4	9.5	2.7	0	
Middle	15	5	2	0	22	7	7	3	4	0	1	22
	68.2	22.7	9.1	0	29.7	31.8	31.8	13.6	18.2	0	4.5	29.7
	29.4	35.7	40.0	0	(37.2)	22.6	36.8	37.5	30.8	0	100.0	(40.8)
	20.3	6.8	2.7	0		9.5	9.5	4.1	5.4	0	1.4	
High	28	2	0	2	32	20	9	1	2	0	0	32
	87.5	6.3	0	6.3	43.2	62.5	28.1	3.1	6.3	0	0	43.2
	54.9	14.3	0	50.0	(30.9)	64.5	47.4	12.5	15.4	0	0	(27.3)
	37.8	2.7	0	2.7		27.0	12.2	1.4	2.7	0	0	
Total	51	14	5	4	74	31	19	8	13	2	1	74
	68.9	18.9	6.8	5.4	100.0	41.9	25.7	10.8	17.6	2.7	1.4	100.0
		KW Chi Square		12.10				KW Chi Square		16.32		
		df		6				df		10		
		Significance		.002				Significance		.0003		

Table 169

Interview Data Analyses: Moles - Total
High, Middle or Low Success on Tests

Success on Tests	Problems Correct					Questions Correct					
	0	1	2	3	Total	2	3	4	5	6	Total
Low	12	5	3	0	20	2	6	6	4	2	20
	60.0	25.0	15.0	0	27.0	10.0	30.0	30.0	20.0	10.0	27.0
	44.4	31.3	13.0	0	(25.5)	50.0	85.7	50.0	23.5	5.9	(20.0)
	16.2	6.8	4.1	0		2.7	8.1	8.1	5.4	2.7	
Middle	9	6	6	1	22	0	0	4	7	11	22
	40.9	27.3	27.3	4.5	29.7	0	0	18.2	31.8	50.0	29.7
	33.3	37.5	26.1	12.5	(33.6)	0	0	33.3	41.2	32.4	(42.1)
	12.2	8.1	8.1	1.4		0	0	5.4	9.5	14.9	
High	6	5	14	7	32	2	1	2	6	21	32
	18.8	15.6	43.8	21.9	43.2	6.3	3.1	6.3	18.8	65.6	43.2
	22.2	31.3	60.9	87.5	(47.7)	50.0	14.3	16.7	35.3	61.8	(45.2)
	8.1	6.8	18.9	9.5		2.7	1.4	2.7	8.1	28.4	
Total	27	16	23	8	74	4	7	12	17	34	74
	36.5	21.6	31.1	10.8	100.0	5.4	9.5	16.2	23.0	45.9	100.0

	Problems Correct		Questions Correct
KW Chi Square	15.44	KW Chi Square	20.68
df	6	df	8
Significance	.0004	Significance	<.0001

Table 170

Interview Data Analyses: Moles - Total
High, Middle or Low Success on Tests

Success on Tests	Questions Correct Without Prompting							
	0	1	2	3	4	5	6	Total
Low	1	2	10	3	3	1	0	20
	5.0	10.0	50.0	15.0	15.0	5.0	0	27.0
	33.3	50.0	62.5	23.1	21.4	5.6	0	(22.4)
	1.4	2.7	13.5	4.1	4.1	1.4	0	
Middle	1	0	5	8	4	4	0	22
	4.5	0	22.7	36.4	18.2	18.2	0	29.7
	33.3	0	31.3	61.5	28.6	22.2	0	(33.3)
	1.4	0	6.8	10.8	5.4	5.4	0	
High	1	2	1	2	7	13	6	32
	3.1	6.3	3.1	6.3	21.9	40.6	18.8	43.2
	33.3	50.0	6.3	15.4	50.0	72.2	100.0	(49.9)
	1.4	2.7	1.4	2.7	9.5	17.6	8.1	
Total	3	4	16	13	14	18	6	74
	4.1	5.4	21.6	17.6	18.9	24.3	8.1	100.0

KW Chi Square 22.11
df 12
Significance < .0001

Table 171

Interview Data Analyses: Gas Laws - Problem 1 High, Middle or Low Success on Tests

Success on Tests	Algorithmic Reasoning Strategy		
	0	1	Total
Low	15	4	19
	78.9	21.1	29.7
	39.5	15.4	
	23.4	6.3	
Middle	16	9	25
	64.0	36.0	39.1
	42.1	34.6	
	25.0	14.1	
High	7	13	20
	35.0	65.0	31.3
	18.4	50.0	
	10.9	20.0	
Total	38	26	64
	59.4	40.6	100.0

Chi Square	8.17
df	2
V	.36
Significance	.02

Table 172

Interview Data Analyses: Gas Laws - Problem 2
High, Middle or Low Success on Tests

Success on Tests	Algorithmic Reasoning Strategy			Executive Errors			
	0	1	Total	0	1	2	Total
Low	11	8	19	14	4	1	19
	57.9	42.1	29.7	73.7	21.1	5.3	29.7
	30.6	28.6		27.5	33.3	100.0	(33.1)
	17.2	12.5		21.9	6.3	1.6	
Middle	19	6	25	21	4	0	25
	76.0	24.0	39.1	84.0	16.0	0	39.1
	52.8	21.4		41.2	33.3	0	(37.1)
	29.7	9.4		32.8	6.3	0	
High	6	14	20	16	4	0	20
	30.0	70.0	31.3	80.0	20.0	0	31.3
	16.7	50.0		31.4	33.3	0	(26.2)
	9.4	21.9		25.0	6.3	0	
Total	36	28	64	51	12	1	64
	56.3	43.8	100.0	79.7	18.8	1.6	100.0

Chi Square	9.58
df	2
V	.39
Significance	.008

KW Chi Square	6.10
df	4
Significance	.05

Table 173

Interview Data Analyses: Gas Laws - Problem 3
High, Middle or Low Success on Tests

Success on Tests	Algorithmic Reasoning Strategy			Structural Error 2								
	0	1	Total	0	1	2	3	4	7	8	9	Total
Low	18	1	19	9	0	1	0	4	1	1	3	19
	94.7	5.3	29.7	47.4	0	5.3	0	21.1	5.3	5.3	15.8	27.7
	34.6	8.3		34.6	0	11.1	0	30.8	16.7	33.3	60.0	
	28.1	1.6		14.1	0	1.6	0	6.3	1.6	1.6	4.7	
Middle	24	1	25	13	1	0	1	5	1	2	2	25
	96.0	4.0	39.1	52.0	4.0	0	4.0	20.0	4.0	8.0	8.0	39.1
	46.2	8.3		50.0	100.0	0	100.0	38.5	16.7	66.7	40.0	
	37.5	1.6		20.3	1.6	0	1.6	7.8	1.6	3.1	3.1	
High	10	10	20	4	0	8	0	4	4	0	0	20
	50.0	50.0	31.3	20.0	0	40.0	0	20.0	20.0	0	0	31.3
	19.2	83.3		15.4	0	88.9	0	30.8	66.7	0	0	
	15.6	15.6		6.3	0	12.5	0	6.3	6.3	0	0	
Total	52	12	64	26	1	9	1	13	6	3	5	64
	81.3	18.8	100.0	40.6	1.6	14.1	1.6	20.3	9.4	4.7	7.8	100.0

Chi Square	18.66	Chi Square	28.53
df	2	df	14
V	.54	V	.47
Significance	.0001	Significance	.01

Table 174

Interview Data Analyses: Gas Laws - Total
High, Middle or Low Success on Tests

Success on Tests	Systemmatic Approach					Algorithmic Reasoning Strategy				
	0	1	2	3	Total	0	1	2	3	Total
Low	3 15.8 75.0 4.7	2 10.5 50.0 3.1	9 47.4 26.5 14.1	5 26.3 22.7 7.8	19 29.7 (27.2)	11 57.9 36.7 17.2	3 15.8 30.0 4.7	5 26.3 31.3 7.8	0 0 0 0	19 29.7 (27.3)
Middle	1 4.0 25.0 1.6	2 8.0 50.0 3.1	16 64.0 47.1 25.0	6 24.0 27.3 9.4	25 39.1 (29.8)	16 64.0 53.3 25.0	3 12.0 30.0 4.7	5 20.0 31.3 7.8	1 4.0 12.5 1.6	25 39.1 (26.3)
High	0 0 0 0	0 0 0 0	9 45.0 26.5 14.1	11 55.0 50.0 17.2	20 31.3 (40.9)	3 15.0 10.0 4.7	4 20.0 40.0 6.3	6 30.0 37.5 9.4	7 35.0 87.5 10.9	20 31.3 (45.1)
Total	4 6.3	4 6.3	34 53.1	22 34.4	64 100.0	30 46.9	10 15.6	16 25.0	8 12.5	64 100.0

KW Chi Square	7.57	KW Chi Square	15.37
df	6	df	6
Significance	.02	Significance	.0005

Table 175

Interview Data Analyses: Gas Laws - Total
High, Middle or Low Success on Tests

Success on Tests	Problems Correct				
	0	1	2	3	Total
	15	2	2	0	19
	78.9	10.5	10.5	0	29.7
Low	46.9	11.1	16.7	0	(27.9)
	23.4	3.1	3.1	0	
	9	12	4	0	25
	36.0	48.0	16.0	0	39.1
Middle	28.1	66.7	33.3	0	(32.2)
	14.1	18.8	6.3	0	
	8	4	6	2	20
	40.0	20.0	30.0	10.0	31.3
High	25.0	22.2	50.0	100.0	(37.3)
	12.5	6.3	9.4	3.1	
Total	32	18	12	2	64
	50.0	28.1	18.8	3.1	100.0

KW Chi Square	8.14
df	6
Significance	.02

Table 176

Interview Data Analyses: Stoichiometry - Problem 1
High, Middle or Low Success on Tests

Success on Tests	Use of Mneumonic Notation			Systemmatic Approach			Arithmetic Approach		
	0	1	Total	0	1	Total	0	1	Total
	9	12	21	8	13	21	15	6	21
	42.9	57.1	31.8	38.1	61.9	31.8	71.4	28.6	31.8
Low	34.6	30.0	(32.4)	42.1	27.7		36.6	24.0	
	13.6	18.2		12.1	19.7		22.7	9.1	
	13	11	24	11	13	24	18	6	24
	54.2	45.8	36.4	45.8	54.2	36.4	75.0	25.0	36.4
Middle	50.0	27.5	(28.6)	57.9	27.7		43.9	24.0	
	19.7	16.7		16.7	19.7		27.3	9.1	
	4	17	21	0	21	21	8	13	21
	19.0	81.0	31.8	0	100.0	31.8	38.1	61.9	31.8
High	15.4	42.5	(40.2)	0	44.7		19.5	52.0	
	6.1	25.8		0	31.8		12.1	19.7	
Total	26	40	66	19	47	66	41	25	66
	39.4	60.6	100.0	28.8	71.2	100.0	62.1	37.9	100.0
	KW Chi Square		5.85	Chi Square		12.78	Chi Square		7.62
	df		2	df		2	df		2
				V		.44	V		.34
	Significance		.05	Significance		.002	Significance		.02

Table 177

Interview Data Analyses: Stoichiometry - Problem 1
High, Middle or Low Success on Tests

Success on Tests	Nonsystemmatic Approach			No Answer Given			Comments About Solution			
	0	1	Total	0	1	Total	0	1	2	Total
Low	15 71.4 27.3 22.7	6 28.6 54.5 9.1	21 31.8	19 90.5 32.8 28.8	2 9.5 25.0 3.0	21 31.8	7 33.3 21.2 10.6	14 66.7 45.2 21.2	0 0 0 0	21 31.8 (38.3)
Middle	19 79.2 34.5 28.8	5 20.8 45.5 7.6	24 36.4	18 75.0 31.0 27.3	6 25.0 75.0 9.1	24 36.4	8 33.3 24.2 12.1	14 58.3 45.2 21.2	2 8.3 100.0 3.0	24 36.4 (39.7)
High	21 100.0 38.2 31.8	0 0 0 0	21 31.8	21 100.0 36.2 31.8	0 0 0 0	21 31.8	18 85.7 54.5 27.3	3 14.3 9.7 4.5	0 0 0 0	21 31.8 (21.6)
Total	55 83.3	11 16.7	66 100.0	58 87.9	8 12.1	66 100.0	33 50.0	31 47.0	2 3.0	66 100.0
	Chi Square df V Significance		6.64 2 .32 .04	Chi Square df V Significance		6.77 2 .32 .03	KW Chi Square df Significance		15.49 4 .0004	

Table 178

Interview Data Analyses: Stoichiometry - Problem 1
High, Middle or Low Success on Tests

Success on Tests	Algorithmic Reasoning Strategy			Structural Error - 2				
	0	1	Total	0	1	2	3	Total
Low	18	3	21	1	11	0	9	21
	85.7	14.3	31.8	4.8	52.4	0	42.9	31.8
	38.3	15.8		11.1	34.4	0	42.9	
	27.3	4.5		1.5	16.7	0	13.6	
Middle	21	3	24	8	7	3	6	24
	87.5	12.5	36.4	33.3	29.2	12.5	25.0	36.4
	44.7	15.8		88.9	21.9	75.0	28.6	
	31.8	4.5		12.1	10.6	4.5	9.1	
High	8	13	21	0	14	1	6	21
	38.1	61.9	31.8	0	66.7	4.8	28.6	31.8
	17.0	68.4		0	43.8	25.0	28.6	
	12.1	19.7		0	21.2	1.5	9.1	
Total	47	19	66	9	32	4	21	66
	71.2	28.8	100.0	13.6	48.5	6.1	31.8	100.0

Algorithmic Reasoning Strategy		Structural Error - 2	
Chi Square	16.49	Chi Square	18.45
df	2	df	6
V	.50	V	.37
Significance	.0003	Significance	.005

Table 179

Interview Data Analyses: Stoichiometry - Problem 2
High, Middle or Low Success on Tests

Success on Tests	Systemmatic Approach			Arithmetic Approach			Nonsystemmatic Approach		
	0	1	Total	0	1	Total	0	1	Total
Low	8	13	21	17	4	21	17	4	21
	38.1	61.9	31.8	81.0	19.0	31.8	81.0	19.0	31.8
	40.0	28.3		35.4	22.2		30.9	36.4	
	12.1	19.7		25.8	6.1		25.8	6.1	
Middle	11	13	24	20	4	24	17	7	24
	45.8	54.2	36.4	83.3	16.7	36.4	70.8	29.2	36.4
	55.0	28.3		41.7	22.2		30.9	63.6	
	16.7	19.7		30.3	6.1		25.8	10.6	
High	1	20	21	11	10	21	21	0	21
	4.8	95.2	31.8	52.4	47.6	31.8	100.0	0	31.8
	5.0	43.5		22.9	55.6		38.2	0	
	1.5	30.3		16.7	15.2		31.8	0	
Total	20	46	66	48	18	66	55	11	66
	30.3	69.7	100.0	72.7	27.3	100.0	83.3	16.7	100.0
	Chi Square		9.83	Chi Square		6.46	Chi Square		6.99
	df		2	df		2	df		2
	V		.38	V		.31	V		.32
	Significance		.007	Significance		.04	Significance		.03

Table 180

Interview Data Analyses: Stoichiometry - Problem 2
High, Middle or Low Success on Tests

Success on Tests	Algorithmic Reasoning Strategy 0	1	Total	Comments About Solution 0	1	2	Total
Low	18	3	21	13	8	0	21
	85.7	14.3	31.8	61.9	38.1	0	31.8
	39.1	15.0		37.1	27.6	0	(30.2)
	27.3	4.5		19.7	12.1	0	
Middle	21	3	24	7	16	1	24
	87.5	12.5	36.4	29.2	66.7	4.2	36.4
	45.7	15.0		20.0	55.2	50.0	(41.3)
	31.8	4.5		10.6	24.2	1.5	
High	7	14	21	15	5	1	21
	33.3	66.7	31.8	71.4	23.8	4.8	31.8
	15.2	70.0		42.9	17.2	50.0	(27.9)
	10.6	21.2		22.7	7.6	1.5	
Total	46	20	66	35	29	2	66
	69.7	30.3	100.0	53.0	43.9	3.0	100.0

Chi Square	19.30	KW Chi Square	8.35
df	2	df	4
Phi	.54	Significance	.02
Significance	.0001		

Table 181

Interview Data Analyses: Stoichiometry - Problem 2
High, Middle or Low Success on Tests

Success on Tests	Structural Error - 2				
	0	1	2	3	Total
	5	6	5	5	21
	23.8	28.6	23.8	23.8	31.8
Low	38.5	26.1	41.7	27.8	
	7.6	9.1	7.6	7.6	
	7	4	4	9	24
	29.2	16.7	16.7	37.5	36.4
Middle	53.8	17.4	33.3	50.0	
	10.6	6.1	6.1	13.6	
	1	13	3	4	21
	4.8	61.9	14.3	19.0	31.8
High	7.7	56.5	25.0	22.2	
	1.5	19.7	4.5	6.1	
Total	13	23	12	18	66
	19.7	34.8	18.2	27.3	100.0

Chi Square	12.68
df	6
V	.31
Significance	.05

Table 182

Interview Data Analyses: Stoichiometry - Problem 3
High, Middle or Low Success on Tests

Success on Tests	Algorithmic Reasoning Strategy 0	1	Total	Executive Errors 0	1	Total	Structural Error - 3 0	1	2	3	Total
Low	20	1	21	21	0	21	12	2	3	4	21
	95.2	4.8	31.8	100.0	0	31.8	57.1	9.5	14.3	19.0	31.8
	35.7	10.0		34.4	0		31.6	18.2	30.0	57.1	
	30.3	1.5		31.8	0		18.2	3.0	4.5	6.1	
Middle	23	1	24	24	0	24	17	1	5	1	24
	95.8	4.2	36.4	100.0	0	36.4	70.8	4.2	20.8	4.2	36.4
	41.1	10.0		39.3	0		44.7	9.1	50.0	14.3	
	34.8	1.5		36.4	0		25.8	1.5	7.6	1.5	
High	13	8	21	16	5	21	9	8	2	2	21
	61.9	38.1	31.8	76.2	23.8	31.8	42.9	38.1	9.5	9.5	31.8
	23.2	80.0		26.2	100.0		23.7	72.7	20.0	28.6	
	19.7	12.1		24.2	7.6		13.6	12.1	3.0	3.0	
Total	56	10	66	61	5	66	38	11	10	7	66
	84.8	15.2	100.0	92.4	7.6	100.0	57.6	16.7	15.2	10.6	100.0

Algorithmic Reasoning Strategy		Executive Errors		Structural Error - 3	
Chi Square	12.61	KW Chi Square	11.42	Chi Square	13.54
df	2	df	2	df	6
V	.44	Significance	.003	V	.32
Significance	.002			Significance	.04

Table 183

Interview Data Analyses: Stoichiometry - Total
High, Middle or Low Success on Tests

Success on Tests	Systemmatic Approach					Arithmetic Approach				
	0	1	2	3	Total	0	1	2	3	Total
Low	6	3	4	8	21	14	3	1	3	21
	28.6	14.3	19.0	38.1	31.8	66.7	14.3	4.8	14.3	31.8
	40.0	37.5	33.3	25.8	(30.1)	35.9	30.0	33.3	21.4	(30.6)
	9.1	4.5	6.1	12.1		21.2	4.5	1.5	4.5	
Middle	9	4	2	9	24	17	4	0	3	24
	37.5	16.7	8.3	37.5	36.4	70.8	16.7	0	12.5	36.4
	60.0	50.0	16.7	29.0	(27.8)	43.6	40.0	0	21.4	(29.0)
	13.6	6.1	3.0	13.6		25.8	6.1	0	4.5	
High	0	1	6	14	21	8	3	2	8	21
	0	4.8	28.6	66.7	31.8	38.1	14.3	9.5	38.1	31.8
	0	12.5	50.0	45.2	(43.4)	20.5	30.0	66.7	57.1	(41.5)
	0	1.5	9.1	21.2		12.1	4.5	3.0	12.1	
Total	15	8	12	31	66	39	10	3	14	66
	22.7	12.1	18.2	47.0	100.0	59.1	15.2	4.5	21.2	100.0

	Systemmatic Approach		Arithmetic Approach
KW Chi Square	9.44	KW Chi Square	6.95
df	6	df	6
Significance	.009	Significance	.03

Table 184

Interview Data Analyses: Stoichiometry - Total
High, Middle or Low Success on Tests

Success on Tests	Nonsystemmatic Approach 0	1	2	3	Total	Algorithmic Reasoning Strategy 0	1	2	3	Total
Low	14	3	1	3	21	18	0	2	1	21
	66.7	14.3	4.8	14.3	31.8	85.7	0	9.5	4.8	31.8
	29.8	30.0	25.0	60.0	(35.5)	40.0	0	25.0	10.0	(27.6)
	21.2	4.5	1.5	4.5		27.3	0	3.0	1.5	
Middle	14	5	3	2	24	21	0	2	1	24
	58.3	20.8	12.5	8.3	36.4	87.5	0	8.3	4.2	36.4
	29.8	50.0	75.0	40.0	(37.7)	46.7	0	25.0	10.0	(27.1)
	21.2	7.6	4.5	3.0		31.8	0	3.0	1.5	
High	19	2	0	0	21	6	3	4	8	21
	90.5	9.5	0	0	31.8	28.6	14.3	19.0	38.1	31.8
	40.4	20.0	0	0	(26.7)	13.3	100.0	50.0	80.0	(46.7)
	28.8	3.0	0	0		9.1	4.5	6.1	12.1	
Total	47	10	4	5	66	45	3	8	10	66
	71.2	15.2	6.1	7.6	100.0	68.2	4.5	12.1	15.2	100.0

	Nonsystemmatic Approach	Algorithmic Reasoning Strategy
KW Chi Square	6.30	21.55
df	6	6
Significance	.04	<.0001

Table 185

Interview Data Analyses: Stoichiometry - Total
High, Middle or Low Success on Tests

Success on Tests	Comments About Solution 0	1	2	3	4	Total	Executive Errors 0	1	2	3	Total
Low	3	6	7	5	0	21	19	2	0	0	21
	14.3	28.6	33.3	23.8	0	31.8	90.5	9.5	0	0	31.8
	25.0	30.0	58.3	23.8	0	(33.3)	34.5	25.0	0	0	(31.0)
	4.5	9.1	10.6	7.6	0		28.8	3.0	0	0	
Middle	3	4	1	15	1	24	23	1	0	0	24
	12.5	16.7	4.2	62.5	4.2	36.4	95.8	4.2	0	0	36.4
	25.0	20.0	8.3	71.4	100.0	(43.3)	41.8	12.5	0	0	(29.3)
	4.5	6.1	1.5	22.7	1.5		34.8	1.5	0	0	
High	6	10	4	1	0	21	13	5	2	1	21
	28.6	47.6	19.0	4.8	0	31.8	61.9	23.8	9.5	4.8	31.8
	50.0	50.0	33.3	4.8	0	(22.5)	23.6	62.5	100.0	100.0	(40.8)
	9.1	15.2	6.1	1.5	0		19.7	7.6	3.0	1.5	
Total	12	20	12	21	1	66	55	8	2	1	66
	18.2	30.3	18.2	31.8	1.5	100.0	83.3	12.1	3.0	1.5	100.0

Comments About Solution		Executive Errors	
KW Chi Square	14.13	KW Chi Square	10.78
df	8	df	6
Significance	.0009	Significance	.005

Table 186

Interview Data Analyses: Stoichiometry - Total
High, Middle or Low Success on Tests

Success on Tests	Problems Correct 0	1	2	3	Total	Questions Correct 0	1	2	Total
	13	7	0	1	21	6	5	10	21
	61.9	33.3	0	4.8	31.8	28.6	23.8	47.6	31.8
Low	32.5	43.8	0	25.0	(31.9)	60.0	31.3	25.0	(28.1)
	19.7	10.6	0	1.5		9.1	7.6	15.2	
	20	2	2	0	24	4	8	12	24
	83.3	8.3	8.3	0	36.4	16.7	33.3	50.0	36.4
Middle	50.0	12.5	33.3	0	(26.1)	40.0	50.0	30.0	(30.3)
	30.3	3.0	3.0	0		6.1	12.1	18.2	
	7	7	4	3	21	0	3	18	21
	33.3	33.3	19.0	14.3	31.8	0	14.3	85.7	31.8
High	17.5	43.8	66.7	75.0	(43.5)	0	18.8	45.0	(42.5)
	10.6	10.6	6.1	4.5		0	4.5	27.3	
Total	40	16	6	4	66	10	16	40	66
	60.6	24.2	9.1	6.1	100.0	15.2	24.2	60.6	100.0

	Problems Correct		Questions Correct
KW Chi Square	12.43	KW Chi Square	9.11
df	6	df	4
Significance	.002	Significance	.01

Table 187

Interview Data Analyses: Stoichiometry - Total
High,Middle or Low Success on Tests

Success on Tests	Questions Correct Without Prompting					
	0	1	2	3	4	Total
Low	2	5	5	4	5	21
	9.5	23.8	23.8	19.0	23.8	31.8
	50.0	50.0	26.3	16.0	62.5	(31.9)
	3.0	7.6	7.6	6.1	7.6	
Middle	1	4	11	8	0	24
	4.2	16.7	45.8	33.3	0	36.4
	25.0	40.0	57.9	32.0	0	(28.0)
	1.5	6.1	16.7	12.1	0	
High	1	1	3	13	3	21
	4.8	4.8	14.3	61.9	14.3	31.8
	25.0	10.0	15.8	52.0	37.5	(41.4)
	1.5	1.5	4.5	19.7	4.5	
Total	4	10	19	25	8	66
	6.1	15.2	28.8	37.9	12.1	100.0

KW Chi Square	6.19
df	8
Significance	.05

Table 188

Interview Data Analyses: Molarity - Problem 2
High, Middle or Low Success on Tests

Success on Tests	Use of Random Trial and Error		
	0	1	Total
	13	2	15
	86.7	13.3	27.3
Low	28.3	22.2	
	23.6	3.6	
	17	7	24
	70.8	29.2	43.6
Middle	37.0	77.8	
	30.9	12.7	
	16	0	16
	100.0	0	29.1
High	34.8	0	
	29.1	0	
Total	46	9	55
	83.6	16.4	100.0

Chi Square	6.11
df	2
V	.33
Significance	.05

Table 189

Interview Data Analyses: Molarity - Problem 3
High, Middle or Low Success on Tests

Success on Tests	Arithmetic Approach			Nonsystemmatic Approach			Algorthmic Reasoning Strategy		
	0	1	Total	0	1	Total	0	1	Total
Low	9	6	15	14	1	15	11	4	15
	60.0	40.0	27.3	93.3	6.7	27.3	73.3	26.7	27.3
	25.0	31.6		29.2	14.3		26.2	30.8	
	16.4	10.9		25.5	1.8		20.0	7.3	
Middle	20	4	24	18	6	24	23	1	24
	83.3	16.7	43.6	75.0	25.0	43.6	95.8	4.2	43.6
	55.6	21.1		37.5	85.7		54.8	7.7	
	36.4	7.3		32.7	10.9		41.8	1.8	
High	7	9	16	16	0	16	8	8	16
	43.8	56.3	29.1	100.0	0	29.1	50.0	50.0	29.1
	19.4	47.4		33.3	0		19.0	61.5	
	12.7	16.4		29.1	0		14.5	14.5	
Total	36	19	55	48	7	55	42	13	55
	65.5	34.5	100.0	87.3	12.7	100.0	76.4	23.6	100.0
	Chi Square	6.92		Chi Square	6.08		Chi Square	11.28	
	df	2		df	2		df	2	
	V	.35		V	.33		V	.45	
	Significance	.03		Significance	.05		Significance	.004	

Table 190

Interview Data Analyses: Molarity - Problem 3
High, Middle or Low Success on Tests

Success on Tests	Structural Error - 2						Structural Error - 3				
	0	1	2	3	4	Total	0	1	2	3	Total
Low	5	0	4	2	4	15	6	0	5	4	15
	33.3	0	26.7	13.3	26.7	27.3	40.0	0	33.3	26.7	27.3
	31.3	0	30.8	18.2	80.0		20.0	0	62.5	28.6	
	9.1	0	7.3	3.6	7.3		10.9	0	9.1	7.3	
Middle	7	9	2	5	1	24	19	2	1	2	24
	29.2	37.5	8.3	20.8	4.2	43.6	79.2	8.3	4.2	8.3	43.6
	43.8	90.0	15.4	45.5	20.0		63.3	66.7	12.5	14.3	
	12.7	16.4	3.6	9.1	1.8		34.5	3.6	1.8	3.6	
High	4	1	7	4	0	16	5	1	2	8	16
	25.0	6.3	43.8	25.0	0	29.1	31.3	6.3	12.5	50.0	29.1
	25.0	10.0	53.8	36.4	0		16.7	33.3	25.0	57.1	
	7.3	1.8	12.7	7.3	0		9.1	1.8	3.6	14.5	
Total	16	10	13	11	5	55	30	3	8	14	55
	29.1	18.2	23.6	20.0	9.1	100.0	54.5	5.5	14.5	25.5	100.0

Chi Square	22.00	Chi Square	18.07
df	8	df	6
V	.45	V	.40
Significance	.005	Significance	.006

Table 191

Interview Data Analyses: Molarity - Total High, Middle or Low Success on Tests

Success on Tests	Nonsystemmatic Approach 0	1	2	3	Total	Use of Random Trial and Error 0	1	2	3	Total
Low	9	5	1	0	15	9	5	1	0	15
	60.0	33.3	6.7	0	27.3	60.0	33.3	6.7	0	27.3
	23.7	45.5	25.0	0	(29.8)	23.7	38.5	50.0	0	(30.2)
	16.4	9.1	1.8	0		16.4	9.1	1.8	0	
Middle	14	5	3	2	24	14	7	1	2	24
	58.3	20.8	12.5	8.3	43.6	58.3	29.2	4.2	8.3	43.6
	36.8	45.5	75.0	100.0	(31.5)	36.8	53.8	50.0	100.0	(31.2)
	25.5	9.1	5.5	3.6		25.5	12.7	1.8	3.6	
High	15	1	0	0	16	15	1	0	0	16
	93.8	6.3	0	0	29.1	93.8	6.3	0	0	29.1
	39.5	9.1	0	0	(21.0)	39.5	7.7	0	0	(21.1)
	27.3	1.8	0	0		27.3	1.8	0	0	
Total	38	11	4	2	55	38	13	2	2	55
	69.1	20.0	7.3	3.6	100.0	69.1	23.6	3.6	3.6	100.0

	Nonsystemmatic Approach	Use of Random Trial and Error
KW Chi Square	6.61	6.44
df	6	6
Significance	.04	.04

Table 192

Interview Data Analyses: Molarity - Total High, Middle or Low Success on Tests

Success on Tests	Problems Correct 0	1	2	3	Total
Low	12	0	3	0	15
	80.0	0	20.0	0	27.3
	34.3	0	42.9	0	(24.6)
	21.8	0	5.5	0	
Middle	17	6	1	0	24
	70.8	25.0	4.2	0	43.6
	48.6	50.0	14.3	0	(25.3)
	30.9	10.9	1.8	0	
High	6	6	3	1	16
	37.5	37.5	18.8	6.3	29.1
	17.1	50.0	42.9	100.0	(35.3)
	10.9	10.9	5.5	1.8	
Total	35	12	7	1	55
	63.6	21.8	12.7	1.8	100.0

KW Chi Square	6.46
df	6
Significance	.04

unsuccessful students solving mole problems and moderately successful students on the molarity problems.

Comments about solutions. Moles, all problems (Tables 159, 161, 163, 168), and stoichiometry, problem 1, 2, total (Tables 177,180,185). Unsuccessful students made more comments about the solution for the moles problems whereas moderately successful students made more comments on the stoichiometry problems.

Executive errors. Gas Laws, problem 2 (Table 172) and stoichiometry, problem 3, total (Tables 182, 185). Made more frequently by successful students. Unsuccessful students frequently did not solve the problems and therefore had less opportunities to make executive errors.

Problems correct. Totals for each of four units (Tables 169, 175, 186, 192). Successful students got more problems correct.

Questions correct. Moles (Table 169) and stoichiometry (Table 186). Successful students answered more questions correct on these two units.

Questions correct without prompting. Moles (Table 170) and stoichiometry (Table 187). Successful students answered more questions correct without prompting.

Structural errors. Structural errors are analyzed according to each chemistry unit because there was a unique set of errors associated for each chemistry unit.

1. Gas Laws 3 - 2, Table 173. The major difference between low, middle and high success groups was that the first two groups more frequently did not attempt to start the problem. Successful students' (high group) most frequent error was to not set up a proportion or factor.

2. Stoichiometry 1 - 2, Table 178. Low success students more frequently failed to use the equation in solving a simple stoichiometry problem.

3. Stoichiometry 2 - 2, Table 181 . Low and moderately successful students more frequently failed to use the equation in solving stoichiometry problems than high success students.

4. Stoichiometry 3 - 3, Table 182. This stoichiometry problem was not solved correctly by many students of any category. High success students attempted the problem and used the equation correctly for determining the product. (The major reason for lack of success on this problem appeared to be students' inability to determine the limiting reagent.)

5. Molarity 3 - 2, Table 190. Low success students did not realize that the balanced equation must be used more frequently than middle or high success students.

6. Molarity 3 - 3, Table 190. Low success students used the definition of molarity incorrectly more frequently. More middle success students did not get far enough to use the definition of molarity.

Hypothesis 4

There are no significant differences in chemistry problem solving strategies used by students according to the method taught to solve the problems.

Data were analyzed according to the treatment (method taught) to which they were assigned. This information is summarized in Table 193. Results are summarized in Table 194 and more detailed information about significant findings are given in Tables 195-217.

Systemmatic approach. Stoichiometry, problem 2 (Table 208). Students who used the factor-label methods and the proportion method displayed a more systematic approach more frequently than students who used the other two methods. Because the stoichiometry problems were quite complex this may have important educational implications.

Approach taught. Moles, all problems (Tables 195, 196, 197, 198), gas laws, all problems (Tables 200, 201, 202, 204), stoichiometry, all problems (Tables 206, 208, 210, 212), and molarity, all problems (Tables 214, 215, 216, 217). Students who were taught to use the factor-label method and proportionality more overtly used

Table 193

Distribution of Students According

to Teaching Strategy

Unit	Strategy			
	Factor-Label N	Analogy N	Diagram N	Proportion N
Moles	20	17	24	13
Gas Laws	14	18	16	16
Stoichiometry	19	15	17	17
Molarity	15	19	19	11

Table 194

Summary of Significant Findings: Teaching Strategies

Protocol Categories	Moles				Gas Laws				Stoichiometry				Molarity			
	P1[a]	P2[b]	P3[c]	T[d]	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Reading/Organizing																
Rereads or Stating[g]																
Mneumonics																
Production																
Systematic										13.08[e] .005[f]						
Approach Taught	26.24 <.0001	31.92 <.0001	23.38 <.0001	38.19 <.0001	50.05 <.0001	50.05 <.0001	9.98 .02	53.58 <.0001	31.96 <.0001	36.85 <.0001	17.34 .0006	35.43 <.0001	22.78 <.0001	24.09 <.0001	26.03 <.0001	40.18 <.0001
Arithmetic	12.55 .006	21.28 .0001	12.49 .006	20.49 .0001	37.51 <.0001	40.12 <.0001	9.51 .02	36.34 <.0001	13.58 .004	10.58 .01	7.87 .05	12.85 .005		14.38 .002	8.09 .04	14.69 .002
Nonsystemmatic				7.84 .05					7.77 .05	7.77 .05	12.87 .005	11.36 .01			7.70 .05	
No Answer									7.70 .05	7.61 .05						
Strategy																
Algorithmic						10.78 .01		8.63 .03								
Alg/Reasoning						9.66 .02		7.77 .05								
Random T & E											10.61 .01	9.81 .02				
Structural Error																
Misinterprets																
Disregards given																
Disregards gen																
Misapplies							9.23 .03	12.23 .007								
Not generate			8.63 .03	12.96 .005												

Table 194 (continued)

Summary of Significant Findings: Teaching Strategies

Protocol Categories	Moles				Gas Laws				Stoichiometry				Molarity			
	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Evaluation																
*Comments about Solution							9.23 .03									
*Executive Errors																
*Problems Correct	X[i]	X	X		X	X	X		X	X	X		X	X	X	
*Questions Correct	X	X	X		X	X	X		X	X	X		X	X	X	
*Question w/o Prompting	X	X	X		X	X	X		X	X	X		X	X	X	
Structural Errors																
Section[h] 1 - 1	X	X	X	X		X	X	X		X	X	X		X	X	X
Section 1 - 2	X	X	X	X		X	X	X		X	X	X		X	X	X
Section 2 - 1	X	X	X	X	X		X	X	X		X	X	X		X	X
Section 2 - 2	X	X	X	X	X		X	X	X		X	X	X		X	X
Section 3 - 1	X	X	X	X	X	X		X	X	X		X	X	X		X
Section 3 - 2	X	X	X	X	X	X		X	X	X		X	X	X		X
Section 3 - 3	X	X	X	X	X	X		X	X	X		X	X	X		X

*Category sum

[a] Problem 1

[b] Problem 2

[c] Problem 3

[d] Sum of Problems 1, 2 & 3

[e] Statistic

[f] Probability level

[g] Sum of rereads and restates subcategories

[h] Section on supplementary coding sheet

[i] Not meaningful

Table 195

Interview Data Analyses: Moles - Problem 1
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach		
	0	1	Total	0	1	Total
Factor-Label	9[a]	11	20	13	7	20
	45.0[b]	55.0	27.0	65.0	35.0	27.0
	15.3[c]	73.3		44.8	15.6	
	12.2[d]	14.9		17.6	9.5	
Analogy	17	0	17	5	12	17
	100.0	0	23.0	29.4	70.6	23.0
	28.8	0		17.2	26.7	
	23.0	0		6.8	16.2	
Diagram	24	0	24	4	20	24
	100.0	0	32.4	16.7	83.3	32.4
	40.7	0		13.8	44.4	
	32.4	0		5.4	27.0	
Proportion	9	4	13	7	6	13
	69.2	30.8	17.6	53.8	46.2	17.6
	15.3	26.7		24.1	13.3	
	12.2	5.4		9.5	8.1	
Total	59	15	74	29	45	74
	79.7	20.3	100.0	39.2	60.8	100.0
	Chi Square		26.24	Chi Square		12.55
	df		3	df		3
	V		.59[f]	V		.42
	Significance		<.0001	Significance		.006

[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[f] Cramer's V

Table 196

Interview Data Analyses: Moles - Problem 2
Teaching Strategies

Teaching Strategy	Approach Taught 0	Approach Taught 1	Approach Taught Total	Arithmetic Approach 0	Arithmetic Approach 1	Arithmetic Approach Total
Factor-Label	8	12	20	15	5	20
	40.0	60.0	27.0	75.0	25.0	27.0
	14.5	63.2		45.5	12.2	
	10.8	16.2		20.3	6.8	
Analogy	17	0	17	6	11	17
	100.0	0	23.0	35.3	64.7	23.0
	30.9	0		18.2	26.8	
	23.0	0		8.1	14.9	
Diagram	24	0	24	3	21	24
	100.0	0	32.4	12.5	87.5	32.4
	43.6	0		9.1	51.2	
	32.4	0		4.1	28.4	
Proportion	6	7	13	9	4	13
	46.2	53.8	17.6	69.2	30.8	17.6
	10.9	36.8		27.3	9.8	
	8.1	9.5		12.2	5.4	
Total	55	19	74	33	41	74
	74.3	25.7	100.0	44.6	55.4	100.0

	Approach Taught		Arithmetic Approach
Chi Square	31.92	Chi Square	21.28
df	3	df	3
V	.66	V	.54
Significance	< .0001	Significance	.0001

Table 197

Interview Data Analyses: Moles - Problem 3
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach			Needed Information Not Generated		
	0	1	Total	0	1	Total	0	1	Total
Factor-Label	11	9	20	15	5	20	14	6	20
	55.0	45.0	27.0	75.0	25.0	27.0	70.0	30.0	27.0
	18.6	60.0		33.3	17.2		22.2	54.5	
	14.9	12.2		20.3	6.8		18.9	8.1	
Analogy	17	0	17	11	6	17	15	2	17
	100.0	0	23.0	64.7	35.3	23.0	88.2	11.8	23.0
	28.2	0		24.4	20.7		23.8	18.2	
	23.0	0		14.9	8.1		20.3	2.7	
Diagram	24	0	24	8	16	24	24	0	24
	100.0	0	32.4	33.3	66.7	32.4	100.0	0	32.4
	40.7	0		17.8	55.2		38.1	0	
	32.4	0		10.8	21.6		32.4	0	
Proportion	7	6	13	11	2	13	10	3	13
	53.8	46.2	17.6	84.6	15.4	17.6	76.9	23.1	17.6
	11.9	40.0		24.4	6.9		15.9	27.3	
	9.5	8.1		14.9	2.7		13.5	4.1	
Total	59	15	74	45	29	74	63	11	74
	79.7	20.3	100.0	60.8	39.2	100.0	85.1	14.9	100.0
	Chi Square		23.38	Chi Square		12.49	Chi Square		8.63
	df		3	df		3	df		3
	V		.56	V		.41	V		.34
	Significance		< .0001	Significance		.006	Significance		.03

Table 198

Interview Data Analyses: Moles - Total
Teaching Strategies

Teaching Strategy	Approach Taught					Arithmetic Approach				
	0	1	2	3	Total	0	1	2	3	Total
Factor-Label	5[a]	4	5	6	20	12	2	3	3	20
	25.0[b]	20.0	25.0	30.0	27.0	60.0	10.0	15.0	15.0	27.0
	9.6[c]	100.0	55.6	66.7	(53.8)[e]	52.2	20.0	16.7	13.0	(25.9)
	6.8[d]	5.4	6.8	8.1		16.2	2.7	4.1	4.1	
Analogy	17	0	0	0	17	4	2	6	5	17
	100.0	0	0	0	23.0	23.5	11.8	35.3	29.4	23.0
	32.7	0	0	0	(26.5)	17.4	20.0	33.3	21.7	(39.7)
	23.0	0	0	0		5.4	2.7	8.1	6.8	
Diagram	24	0	0	0	24	0	4	7	13	24
	100.0	0	0	0	32.4	0	16.7	29.2	54.2	32.4
	46.2	0	0	0	(26.5)	0	40.0	38.9	56.5	(51.3)
	32.4	0	0	0		0	5.4	9.5	17.6	
Proportion	6	0	4	3	13	7	2	2	2	13
	46.2	0	30.8	23.1	17.6	53.8	15.4	15.4	15.4	17.6
	11.5	0	44.4	33.3	(47.2)	30.4	20.0	11.1	8.7	(27.1)
	8.1	0	5.4	4.1		9.5	2.7	2.7	2.7	
Total	52	4	9	9	74	23	10	18	23	74
	70.3	5.4	12.2	12.2	100.0	31.1	13.5	24.3	31.1	100.0

KW Chi Square	38.19	KW Chi Square	20.49
df	9	df	9
Significance	< .0001	Significance	.0001

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[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[e] Mean rank

Table 199

Interview Data Analyses: Moles - Total Teaching Strategies

Teaching Strategy	Nonsystemmatic Approach 0	1	2	3	Total	Needed Information Not Generated 0	1	2	Total
Factor-Label	16	2	2	0	20	9	9	2	20
	80.0	10.0	10.0	0	27.0	45.0	45.0	10.0	27.0
	30.8	15.4	33.3	0	(33.9)	17.0	52.9	50.0	(47.3)
	21.6	2.7	2.7	0		12.2	12.2	2.7	
Analogy	8	5	2	2	17	14	2	1	17
	47.1	29.4	11.8	11.8	23.0	82.4	11.8	5.9	23.0
	15.4	38.5	33.3	66.7	(46.5)	26.4	11.8	25.0	(33.8)
	10.8	6.8	2.7	2.7		18.9	2.7	1.4	
Diagram	16	6	2	0	24	22	2	0	24
	66.7	25.0	8.3	0	32.4	91.7	8.3	0	32.4
	30.8	46.2	33.3	0	(38.1)	41.5	11.8	0	(29.9)
	21.6	8.1	2.7	0		29.7	2.7	0	
Proportion	12	0	0	1	13	8	4	1	13
	92.3	0	0	7.7	17.6	61.5	30.8	7.7	17.6
	23.1	0	0	33.3	(30.1)	15.1	23.5	25.0	(41.3)
	16.2	0	0	1.4		10.8	5.4	1.4	
Total	52	13	6	3	74	53	17	4	74
	70.3	17.6	8.1	4.1	100.0	71.6	23.0	5.4	100.0

	Nonsystemmatic Approach	Needed Information Not Generated
KW Chi Square	7.84	12.96
df	9	6
Significance	.05	.005

Table 200

Interview Data Analyses: Gas Laws - Problem 1
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach		
	0	1	Total	0	1	Total
Factor-Label	1	13	14	13	1	14
	7.1	92.9	21.9	92.9	7.1	21.9
	2.6	50.0		40.6	3.1	
	1.6	20.3		20.3	1.6	
Analogy	18	0	18	1	17	18
	100.0	0	28.1	5.6	94.4	28.1
	47.4	0		3.1	53.1	
	28.1	0		1.6	26.6	
Diagram	16	0	16	4	12	16
	100.0	0	25.0	25.0	75.0	25.0
	42.1	0		12.5	37.5	
	25.0	0		6.3	18.8	
Proportion	3	13	16	14	2	16
	18.8	81.3	25.0	87.5	12.5	25.0
	7.9	50.0		43.8	6.3	
	4.7	20.3		21.9	3.1	
Total	38	26	64	32	32	64
	59.4	40.6	100.0	50.0	50.0	100.0

Chi Square	50.05	Chi Square	37.51
df	3	df	3
V	.888	V	.76
Significance	<.0001	Significance	<.0001

Table 201

Interview Data Analyses: Gas Laws - Problem 2
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach			Algorithmic Strategy			Algorithmic Reasoning		
	0	1	Total	0	1	Total	0	1	Total	0	1	Total
Factor-Label	1	13	14	14	0	14	9	5	14	6	8	14
	7.1	92.9	21.9	100.0	0	21.9	64.3	35.7	21.9	42.9	57.1	21.9
	2.6	50.0		42.4	0		25.0	17.9		16.7	28.6	
	1.6	20.3		21.9	0		14.1	7.8		9.4	12.5	
Analogy	18	0	18	2	16	18	10	8	18	10	8	18
	100.0	0	28.1	11.1	88.9	28.1	55.6	44.4	28.1	55.6	44.4	28.1
	47.4	0		6.1	51.6		27.8	28.6		27.8	28.6	
	28.1	0		3.1	25.0		15.6	12.5		15.6	12.5	
Diagram	16	0	16	3	13	16	13	3	16	6	10	16
	100.0	0	25.0	18.8	81.3	25.0	81.3	18.8	25.0	37.5	62.5	25.0
	42.1	0		9.1	41.9		36.1	10.7		16.7	35.7	
	25.0	0		4.7	20.3		20.3	4.7		9.4	15.6	
Proportion	3	13	16	14	2	16	4	12	16	14	2	16
	18.8	81.3	25.0	87.5	12.5	25.0	25.0	75.0	25.0	87.5	12.5	25.0
	7.9	50.0		42.4	6.5		11.1	42.9		38.9	7.1	
	4.7	20.3		21.9	3.1		6.3	18.8		21.9	3.1	
Total	38	26	64	33	31	64	36	28	64	36	28	64
	59.4	40.6	100.0	51.6	48.4	100.0	56.3	43.8	100.0	56.3	43.8	100.0

Chi Square	50.05	Chi Square	40.12	Chi Square	10.78	Chi Square	9.66
df	3	df	3	df	3	df	3
V	.88	V	.79	V	.41	V	.39
Significance	< .0001	Significance	<.0001	Significance	.01	Significance	.02

Table 202

Interview Data Analyses: Gas Laws - Problem 3
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach		
	0	1	Total	0	1	Total
Factor-Label	9	5	14	14	0	14
	64.3	35.7	21.9	100.0	0	21.9
	16.1	62.5		28.6	0	
	14.1	7.8		21.9	0	
Analogy	17	1	18	11	7	18
	94.4	5.6	28.1	61.1	38.9	28.1
	30.4	12.5		22.4	46.7	
	26.6	1.6		17.2	10.9	
Diagram	16	0	16	10	6	16
	100.0	0	25.0	62.5	37.5	25.0
	28.6	0		20.4	40.0	
	25.0	0		15.6	9.4	
Proportion	14	2	16	14	2	16
	87.5	12.5	25.0	87.5	12.5	25.0
	25.0	25.0		28.6	13.3	
	21.9	3.1		21.9	3.1	
Total	56	8	64	49	15	64
	87.5	12.5	100.0	76.6	23.4	100.0

Chi Square	9.98	Chi Square	9.51
df	3	df	3
V	.39	V	.38
Significance	.02	Significance	.02

Table 203

Interview Data Analyses: Gas Laws - Problem 3
Teaching Strategies

Teaching Strategy	Misapplies Information Generated			Comments about Solution			
	0	1	Total	0	1	2	Total
	14	0	14	1	10	3	14
	100.0	0	21.9	7.1	71.4	21.4	21.9
Factor-Label	23.7	0		6.7	22.7	60.0	(40.6)
	21.9	0		1.6	15.6	4.7	
	17	1	18	5	12	1	18
	94.4	5.6	28.1	27.8	66.7	5.6	28.1
Analogy	28.8	20.0		33.3	27.3	20.0	(30.7)
	26.6	1.6		7.8	18.8	1.6	
	12	4	16	7	9	0	16
	75.0	25.0	25.0	43.8	56.3	0	25.0
Diagram	20.3	80.0		46.7	20.5	0	(24.6)
	18.8	6.3		10.9	14.1	0	
	16	0	16	2	13	1	16
	100.0	0	25.0	12.5	81.3	6.3	25.0
Proportion	27.1	0		13.3	29.5	20.0	(35.3)
	25.0	0		3.1	20.3	1.6	
Total	59	5	64	15	44	5	64
	92.2	7.8	100.0	23.4	68.8	7.8	100.0

Chi Square	9.23
df	3
V	.38
Significance	.03

KW Chi Square	9.23
df	6
Significance	.03

Table 204

Interview Data Analyses: Gas Laws - Total
Teaching Strategies

Teaching Strategy	Approach Taught					Arithmetic Approach				
	0	1	2	3	Total	0	1	2	3	Total
Factor-Label	0	1	9	4	14	13	1	0	0	14
	0	7.1	64.3	28.6	21.9	92.9	7.1	0	0	21.9
	0	16.7	50.0	66.7	(52.1)	43.3	33.3	0	0	(16.7)
	0	1.6	14.1	6.3		20.3	1.6	0	0	
Analogy	17	1	0	0	18	1	1	9	7	18
	94.4	5.6	0	0	28.1	5.6	5.6	50.0	38.9	28.1
	50.0	16.7	0	0	(18.6)	3.3	33.3	50.0	53.8	(46.4)
	26.6	1.6	0	0		1.6	1.6	14.1	10.9	
Diagram	16	0	0	0	16	3	1	6	6	16
	100.0	0	0	0	25.0	18.8	6.3	37.5	37.5	25.0
	47.1	0	0	0	(17.5)	10.0	33.3	33.3	46.2	(42.6)
	25.0	0	0	0		4.7	1.6	9.4	9.4	
Proportion	1	4	9	2	16	13	0	3	0	16
	6.3	25.0	59.3	12.5	25.0	81.3	0	18.8	0	25.0
	2.9	66.7	50.0	33.3	(46.0)	43.3	0	16.7	0	(20.6)
	1.6	6.3	14.1	3.1		20.3	0	4.7	0	
Total	34	6	18	6	64	30	3	18	13	64
	53.1	9.4	28.1	9.4	100.0	46.9	4.7	28.1	20.3	100.0

	Approach Taught	Arithmetic Approach
KW Chi Square	53.58	36.34
df	9	9
Significance	<.0001	<.0001

Table 205

Interview Data Analyses: Gas Laws - Total
Teaching Strategies

Teaching Strategy	Algorithmic Strategy Only					Algorithmic Reasoning Strategy					Misapplies Info Generated		
	0	1	2	3	Total	0	1	2	3	Total	0	1	Total
Factor-Label	7	2	4	1	14	5	3	4	2	14	14	0	14
	50.0	14.3	28.6	7.1	21.9	35.7	21.4	28.6	14.3	21.9	100.0	0	21.9
	25.9	20.0	19.0	16.7	(29.8)	16.7	30.0	25.0	25.0	(35.6)	24.1	0	(29.5)
	10.9	3.1	6.3	1.6		7.8	4.7	6.3	3.1		21.9	0	
Analogy	6	5	6	1	18	7	3	6	2	18	17	1	18
	33.3	27.8	33.3	5.6	28.1	38.9	16.7	33.3	11.1	28.1	94.4	5.6	28.1
	22.2	50.0	28.6	16.7	(33.1)	23.3	30.0	37.5	25.0	(34.8)	29.3	16.7	(31.3)
	9.4	7.8	9.4	1.6		10.9	4.7	9.4	3.1		26.6	1.6	
Diagram	11	1	3	1	16	6	2	4	4	16	11	5	16
	68.8	6.3	18.8	6.3	25.0	37.5	12.5	25.0	25.0	25.0	68.8	31.3	25.0
	40.7	10.0	14.3	16.7	(24.5)	20.0	20.0	25.0	50.0	(37.5)	19.0	83.3	(39.5)
	17.2	1.6	4.7	1.6		9.4	3.1	6.3	6.3		17.2	7.8	
Proportion	3	2	8	3	16	12	2	2	0	16	16	0	16
	18.8	12.5	50.0	18.8	25.0	75.0	12.5	12.5	0	25.0	100.0	0	25.0
	11.1	20.0	38.1	50.0	(42.2)	40.0	20.0	12.5	0	(22.1)	27.6	0	(29.5)
	4.7	3.1	12.5	4.7		18.8	3.1	3.1	0		25.0	0	
Total	27	10	21	6	64	30	10	16	8	64	58	6	64
	42.2	15.6	32.8	9.4	100.0	46.9	15.6	25.0	12.5	100.0	90.6	9.4	100.0

	Algorithmic Strategy Only		Algorithmic Reasoning Strategy		Misapplies Info Generated
KW Chi Square	8.63	KW Chi Square	7.77	KW Chi Square	12.23
df	9	df	9	df	3
Significance	.03	Significance	.05	Significance	.007

Table 206

Interview Data Analyses: Stoichiometry - Problem 1
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach			Nonsystemmatic Approach		
	0	1	Total	0	1	Total	0	1	Total
Factor-Label	8	11	19	14	5	19	17	2	19
	42.1	57.9	28.8	73.7	26.3	28.8	89.5	10.5	28.8
	18.2	50.0		34.1	20.0		30.9	18.2	
	12.1	16.7		21.2	7.6		25.8	3.0	
Analogy	15	0	15	6	9	15	9	6	15
	100.0	0	22.7	40.0	60.0	22.7	60.0	40.0	22.7
	34.1	0		14.6	36.0		16.4	54.5	
	22.7	0		9.1	13.6		13.6	9.1	
Diagram	17	0	17	7	10	17	15	2	17
	100.0	0	25.8	41.2	58.8	25.8	88.2	11.8	25.8
	38.6	0		17.1	40.0		27.3	18.2	
	25.8	0		10.6	15.2		22.7	3.0	
Proportion	4	11	15	14	1	15	14	1	15
	26.7	73.3	22.7	93.3	6.7	22.7	93.3	6.7	22.7
	9.1	50.0		34.1	4.0		25.5	9.1	
	6.1	16.7		21.2	1.5		21.2	1.5	
Total	44	22	66	41	25	66	55	11	66
	66.7	33.3	100.0	62.1	37.9	100.0	83.3	16.7	100.0
	Chi Square		31.96	Chi Square		13.58	Chi Square		7.77
	df		3	df		3	df		3
	V		.69	V		.45	V		.34
	Significance		< .0001	Significance		.004	Significance		.05

Table 207

Interview Data Analyses: Stoichiometry - Problem 1
Teaching Strategies

Teaching Stragegy	No Answer Given		
	0	1	Total
Factor-Label	18	1	19
	94.7	5.3	28.8
	31.0	12.5	
	27.3	1.5	
Analogy	15	0	15
	100.0	0	22.7
	25.9	0	
	22.7	0	
Diagram	12	5	17
	70.6	29.4	25.8
	20.7	62.5	
	18.2	7.6	
Proportion	13	2	15
	86.7	13.3	22.7
	22.4	25.0	
	19.7	3.0	
Total	58	8	66
	87.9	12.1	100.0

Chi Square	7.70
df	3
V	.34
Significance	.05

Table 208

Interview Data Analyses: Stoichiometry - Problem 2
Teaching Strategies

Teaching Strategy	Systematic Approach			Approach Taught			Arithmetic Approach		
	0	1	Total	0	1	Total	0	1	Total
Factor-Label	3	16	19	7	12	19	15	4	19
	15.8	84.2	28.8	36.8	63.2	28.8	78.9	21.1	28.8
	15.0	34.8		18.4	42.9		31.3	22.2	
	4.5	24.2		10.6	18.2		22.7	6.1	
Analogy	9	6	15	15	0	15	9	6	15
	60.0	40.0	22.7	100.0	0	22.7	60.0	40.0	22.7
	45.0	13.0		39.5	0		18.8	33.3	
	13.6	9.1		22.7	0		13.6	9.1	
Diagram	7	10	17	15	2	17	9	8	17
	41.2	58.8	25.8	88.2	11.8	25.8	52.9	47.1	25.8
	35.0	21.7		39.5	7.1		18.8	44.4	
	10.6	15.2		22.7	3.0		13.6	12.1	
Proportion	1	14	15	1	14	15	15	0	15
	6.7	93.3	22.7	6.7	93.3	22.7	100.0	0	22.7
	5.0	30.4		2.6	50.0		31.3	0	
	1.5	21.2		1.5	21.2		22.7	0	
Total	20	46	66	38	28	66	48	18	66
	30.3	69.7	100.0	57.6	42.4	100.0	72.7	27.3	100.0
	Chi Square		13.08	Chi Square		36.85	Chi Square		10.58
	df		3	df		3	df		3
	V		.44	V		.75	V		.40
	Significance		.005	Significance		< .0001	Significance		.01

Table 209

Interview Data Analyses: Stoichiometry - Problem 2
Teaching Strategies

Teaching Strategy	Nonsystemmatic Approach			No Answer Given		
	0	1	Total	0	1	Total
Factor-Label	17	2	19	18	1	19
	89.5	10.5	28.8	94.7	5.3	28.8
	30.9	18.2		31.6	11.1	
	25.8	3.0		27.3	1.5	
Analogy	9	6	15	12	3	15
	60.0	40.0	22.7	80.0	20.0	22.7
	16.4	54.5		21.1	33.3	
	13.6	9.1		18.2	4.5	
Diagram	15	2	17	12	5	17
	88.2	11.8	25.8	70.6	29.4	25.8
	27.3	18.2		21.1	55.6	
	22.7	3.0		18.2	7.6	
Proportion	14	1	15	15	0	15
	93.3	6.7	22.7	100.0	0	22.7
	25.5	9.1		26.3	0	
	21.2	1.5		22.7	0	
Total	55	11	66	57	9	66
	83.3	16.7	100.0	86.4	13.6	100.0
	Chi Square		7.77	Chi Square		7.61
	df		3	df		3
	V		.34	V		.34
	Significance		.05	Significance		.05

Table 210

Interview Data Analyses: Stoichiometry - Problem 3
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach		
	0	1	Total	0	1	Total
Factor-Label	11	8	19	15	4	19
	57.9	42.1	28.8	78.9	21.1	28.8
	22.4	47.1		29.4	26.7	
	16.7	12.1		22.7	6.1	
Analogy	15	0	15	11	4	15
	100.0	0	22.7	73.3	26.7	22.7
	30.6	0		21.6	26.7	
	22.7	0		16.7	6.1	
Diagram	16	1	17	10	7	17
	94.1	5.9	25.8	58.8	41.2	25.8
	32.7	5.9		19.6	46.7	
	24.2	1.5		15.2	10.6	
Proportion	7	8	15	15	0	15
	46.7	53.3	22.7	100.0	0	22.7
	14.3	47.1		29.4	0	
	10.6	12.1		22.7	0	
Total	49	17	66	51	15	66
	74.2	25.8	100.0	77.3	22.7	100.0
	Chi Square		17.34	Chi Square		7.87
	df		3	df		3
	V		.51	V		.34
	Significance		.0006	Significance		.05

Table 211

Interview Data Analyses: Stoichiometry - Problem 3
Teaching Strategies

Teaching Strategy	Nonsystemmatic Approach 0	I	Total	Use of Random Trial and Error 0	I	Total
Factor-Label	18	1	19	17	2	19
	94.7	5.3	28.8	89.5	10.5	28.8
	32.7	9.1		33.3	13.3	
	27.3	1.5		25.8	3.0	
Analogy	8	7	15	7	8	15
	53.3	46.7	22.7	46.7	53.3	22.7
	14.5	63.6		13.7	53.3	
	12.1	10.6		10.6	12.1	
Diagram	15	2	17	14	3	17
	88.2	11.8	25.8	82.4	17.6	25.8
	27.3	18.2		27.5	20.0	
	22.7	3.0		21.2	4.5	
Proportion	14	1	15	13	2	15
	93.3	6.7	22.7	86.7	13.3	22.7
	25.5	9.1		25.5	13.3	
	21.2	1.5		19.7	3.0	
Total	55	11	66	51	15	66
	83.3	16.7	100.0	77.3	22.7	100.0

Chi Square	12.87	Chi Square	10.61
df	3	df	3
V	.44	V	.40
Significance	.005	Significance	.01

Table 212

Interview Data Analyses: Stoichiometry - Total
Teaching Strategies

Teaching Strategy	Approach Taught					Arithmetic Approach				
	0	1	2	3	Total	0	1	2	3	Total
	7	1	3	8	19	12	4	0	3	19
	36.8	5.3	15.8	42.1	28.8	63.2	21.1	0	15.8	28.8
Factor-Label	18.4	20.0	42.9	50.0	(41.4)	30.8	40.0	0	21.4	(31.4)
	10.6	1.5	4.5	12.1		18.2	6.1	0	4.5	
	15	0	0	0	15	6	3	2	4	15
	100.0	0	0	0	22.7	40.0	20.0	13.3	26.7	22.7
Analogy	39.5	0	0	0	(19.5)	15.4	30.0	66.7	28.6	(39.6)
	22.7	0	0	0		9.1	4.5	3.0	6.1	
	15	1	1	0	17	7	2	1	7	17
	88.2	5.9	5.9	0	25.8	41.2	11.8	5.9	41.2	25.8
Diagram	39.5	20.0	14.3	0	(22.4)	17.9	20.0	33.3	50.0	(41.0)
	22.7	1.5	1.5	0		10.6	3.0	1.5	10.6	
	1	3	3	8	15	14	1	0	0	15
	6.7	20.0	20.0	53.3	22.7	93.3	6.7	0	0	22.7
Proportion	2.6	60.0	42.9	50.0	(50.1)	35.9	10.0	0	0	(21.6)
	1.5	4.5	4.5	12.1		21.2	1.5	0	0	
Total	38	5	7	16	66	39	10	3	14	66
	57.6	7.6	10.6	24.2	100.0	59.1	15.2	4.5	21.2	100.0

	Approach Taught		Arithmetic Approach
KW Chi Square	35.43	KW Chi Square	12.85
df	9	df	9
Significance	< .0001	Significance	.005

Table 213

Interview Data Analyses: Stoichiometry - Total Teaching Strategies

Teaching Strategy	Nonsystemmatic Approach					Use of Random Trial and Error				
	0	1	2	3	Total	0	1	2	3	Total
Factor-Label	16	1	2	0	19	14	1	4	0	19
	84.2	5.3	10.5	0	28.8	73.7	5.3	21.1	0	28.8
	34.0	10.0	50.0	0	(29.2)	32.6	9.1	66.7	0	(30.9)
	24.2	1.5	3.0	0		21.2	1.5	6.1	0	
Analogy	6	3	2	4	15	5	4	2	4	15
	40.0	20.0	13.3	26.7	22.7	33.3	26.7	13.3	26.7	22.7
	12.8	30.0	50.0	80.0	(45.1)	11.6	36.4	33.3	66.7	(45.0)
	9.1	4.5	3.0	6.1		7.6	6.1	3.0	6.1	
Diagram	13	3	0	1	17	13	3	0	1	17
	76.5	17.6	0	5.9	25.8	76.5	17.6	0	5.9	25.8
	27.7	30.0	0	20.0	(31.4)	30.2	27.3	0	16.7	(29.2)
	19.7	4.5	0	1.5		19.7	4.5	0	1.5	
Proportion	12	3	0	0	15	11	3	0	1	15
	80.0	20.0	0	0	22.7	73.3	20.0	0	6.7	22.7
	25.5	30.0	0	0	(29.7)	25.6	27.3	0	16.7	([illegible].2)
	18.2	4.5	0	0		16.7	4.5	0	1.5	
Total	47	10	4	5	66	43	11	6	6	66
	71.2	15.2	6.1	7.6	100.0	65.2	16.7	9.1	9.1	100.0

KW Chi Square	11.36	KW Chi Square	9.81
df	9	df	9
Significance	.01	Significance	.02

Table 214

Interview Data Analyses: Molarity - Problem 1
Teaching Strategies

Teaching Strategy	Approach Taught 0	Approach Taught 1	Total
Factor-Label	7	8	15
	46.7	53.3	23.4
	13.5	66.7	
	10.9	12.5	
Analogy	19	0	19
	100.0	0	29.7
	36.5	0	
	29.7	0	
Diagram	19	0	19
	100.0	0	29.7
	36.5	0	
	29.7	0	
Proportion	7	4	11
	63.6	36.4	17.2
	13.5	33.3	
	10.9	6.3	
Total	52	12	64
	81.3	18.8	100.0

Chi Square	22.78
df	3
V	.60
Significance	< .0001

Table 215

Interview Data Analyses: Molarity - Problem 2
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach		
	0	1	Total	0	1	Total
Factor-Label	8	7	15	10	5	15
	53.3	46.7	23.4	66.7	33.3	23.4
	15.7	53.8		34.5	14.3	
	12.5	10.9		15.6	7.8	
Analogy	19	0	19	6	13	19
	100.0	0	29.7	31.6	68.4	29.7
	37.3	0		20.7	37.1	
	29.7	0		9.4	20.3	
Diagram	19	0	19	4	15	19
	100.0	0	29.7	21.1	78.9	29.7
	37.3	0		13.8	42.9	
	29.7	0		6.3	23.4	
Proportion	5	6	11	9	2	11
	45.5	54.5	17.2	81.8	18.2	17.2
	9.8	46.2		31.0	5.7	
	7.8	9.4		14.1	3.1	
Total	51	13	64	29	35	64
	79.7	20.3	100.0	45.3	54.7	100.0

Chi Square	24.09	Chi Square	14.63
df	3	df	3
V	.61	V	.48
Significance	<.0001	Significance	.002

Table 216

Interview Data Analyses: Molarity - Problem - 3
Teaching Strategies

Teaching Strategy	Approach Taught			Arithmetic Approach			Nonsystemmatic Approach		
	0	1	Total	0	1	Total	0	1	Total
Factor-Label	6	9	15	13	2	15	15	0	15
	40.0	60.0	23.4	86.7	13.3	23.4	100.0	0	23.4
	11.8	69.2		29.5	10.0		27.3	0	
	9.4	14.1		20.3	3.1		23.4	0	
Analogy	19	0	19	11	8	19	13	6	19
	100.0	0	29.7	57.9	42.1	29.7	68.4	31.6	29.7
	37.3	0		25.0	40.0		23.6	66.7	
	29.7	0		17.2	12.5		20.3	9.4	
Diagram	19	0	19	10	9	19	17	2	19
	100.0	0	29.7	52.6	47.4	29.7	89.5	10.5	29.7
	37.3	0		22.7	45.0		30.9	22.2	
	29.7	0		15.6	14.1		26.6	3.1	
Proportion	7	4	11	10	1	11	10	1	11
	63.6	36.4	17.2	90.9	9.1	17.2	90.9	9.1	17.2
	13.7	30.8		22.7	5.0		18.2	11.1	
	10.9	6.3		15.6	1.6		15.6	1.6	
Total	51	13	64	44	20	64	55	9	64
	79.7	20.3	100.0	68.8	31.3	100.0	85.9	14.1	100.0
	Chi Square		26.03	Chi Square		8.09	Chi Square		7.70
	df		3	df		3	df		3
	V		.64	V		.35	V		.35
	Significance		< .0001	Significance		.04	Significance		.05

Table 217

Interview Data Analyses: Molarity - Total Teaching Strategies

Teaching Strategy	Approach Taught					Arithmetic Approach				
	0	1	2	3	Total	0	1	2	3	Total
Factor-Label	4	4	1	6	15	8	2	4	1	15
	26.7	26.7	6.7	40.0	23.4	53.3	13.3	26.7	6.7	23.4
	9.1	50.0	16.7	100.0	(47.2)	38.1	22.2	21.1	6.7	(23.8)
	6.3	6.3	1.6	9.4		12.5	3.1	6.3	1.6	
Analogy	19	0	0	0	19	5	0	8	6	19
	100.0	0	0	0	29.7	26.3	0	42.1	31.6	29.7
	43.2	0	0	0	(22.5)	23.8	0	42.1	40.0	(37.7)
	29.7	0	0	0		7.8	0	12.5	9.4	
Diagram	19	0	0	0	19	2	4	5	8	19
	100.0	0	0	0	29.7	10.5	21.1	26.3	42.1	29.7
	43.2	0	0	0	(22.5)	9.5	44.4	26.3	53.3	(41.2)
	29.7	0	0	0		3.1	6.3	7.8	12.5	
Proportion	2	4	5	0	11	6	3	2	0	11
	18.2	36.4	45.5	0	17.2	54.5	27.3	18.2	0	17.2
	4.5	50.0	83.3	0	(47.0)	28.6	33.3	10.5	0	(20.4)
	3.1	6.3	7.8	0		9.4	4.7	3.1	0	
Total	44	8	6	6	64	21	9	19	15	64
	68.8	12.5	9.4	9.4	100.0	32.8	14.1	29.7	23.4	100.0

Approach Taught		Arithmetic Approach	
KW Chi Square	40.18	KW Chi Square	14.69
df	9	df	9
Significance	<.0001	Significance	.002

the method taught than students taught by the diagram or the analogy methods. Students may have forgotten the diagram or used the analogies covertly.

Arithmetic approach. Moles, all problems (Tables 195, 196, 197, 198), gas laws, all problems (Tables 200, 201, 202, 204), stoichiometry, all problems (Tables 206, 208, 210, 212) and molarity, problems 2, 3, total (Tables 215, 216, 217). Students taught using the analogy and diagram methods used arithmetic instead of the approach taught.

Nonsystemmatic approach. Moles, total (Table 199), stoichiometry, all problems (Tables 206, 209, 211, 213), and molarity, problem 3 (Table 236). Students who used the analogy and diagrammatic methods were nonsystemmatic more frequently when solving moles problems. Students using the analogy method were nonsystemmatic more frequently solving stoichiometry problems and for molarity problem 3.

No answer given. Stoichiometry, problems 1, 2 (Tables 207, 209). Students who used the diagramic method gave no answers more frequently.

Algorithmic strategy. Gas laws, problem 2, total (Tables 201, 205). Students taught the proportional method used an algorithmic strategy more frequently.

Algorithmic/reasoning strategy. Gas laws, problem 2, total (Tables 201, 205). This strategy was used primarily by students taught by the analogy method and least by students taught by the proportionality methods.

Random trial and error. Stoichiometry, problem 3, total (Tables 211, 213). This strategy was used primarily by persons taught the analogy method.

Misapplies information. Gas laws, problem 3, total (Tables 203, 205). Students taught by the diagram method more frequently misapplied relevant information generated in previous steps.

Does not generate. Moles, problem 3, total (Tables 197, 199). Students who used the factor-label method more frequently did not generate information from memory needed to solve the problem. The next most prevalent method was the proportionality method.

Comments about solution. Gas laws, problem 3 (Table 203). Students who used the factor-label method commented about the solution most frequently, whereas students who used the proportionality method commented least frequently.

Hypothesis 5

There are no significant differences in chemistry problem solving strategies used by students who solved the problem correctly versus those who did not.

Data were analyzed according to whether the student gave a correct answer to the problem. Table 218 gives information on the number of students getting each problem correct. Table 219 summarizes the findings and Tables 220-282 give details when findings were significant.

Reading/organizing. Gas laws, problem 2 (Table 243). Generally students who got the problem correct used more of these skills. However, there was a group of students that used organizing skills frequently who missed the problems.

Rereads or states. Gas laws, problem 2 (Table 243) and stoichiometry, problem 2 (Table 256). Students who reread or restated the problem more frequently did not work the problem correctly.

Mneumonics. Gas laws, total (Table 250). In general, students who used mneumonic notation were more likely to get the problem correct.

Systemmatic approach. Moles, problems 1, 3, total (Tables 220, 230, 234) stoichiometry, all problems (Tables 252, 255, 259, 262) and molarity, problems 1, 3, total (Tables 265, 276, 279). Students who used a systemmatic approach more frequently got the problem correct.

Arithmetic approach. Moles, all problems, (Tables 220, 225, 230, 234), and molarity, problem 1 (Table 265). Students who got the problem correct more frequently used an arithmetic approach.

Table 218

Distribution of Students According to Success on Problems

Unit	Problem 1		Problem 2		Problem 3	
	Correct	Incorrect	Correct	Incorrect	Correct	Incorrect
Moles	39	35	35	39	12	62
Gas Laws	29	35	17	47	2	62
Stoichiometry	18	48	17	49	5	61
Molarity	19	45	8	56	10	54

Table 219

Summary of Significant Findings: Problem Solved Correctly

	Moles				Gas Laws				Stoichiometry				Molarity			
Protocol Categories	P1[a]	P2[b]	P3[c]	T[d]	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Reading/Organizing						518[e] .05[f]										
Rereads or Stating[g]						512 .03				533 .05						
Mneumonics								8.01 .05								
Production																
Systemmatic	16.72 <.0001		7.86 .005	15.37 .001					5.05 .02	8.12 .004	3.73 .05	16.38 .001	6.52 .01		8.35 .004	14.68 .002
Approach Taught																
Arithmetic	13.78 .0002	8.19 .004	9.61 .002	21.29 .0001									3.79 .05			
Nonsystemmatic	7.76 .005			8.99 .03												9.95 .02
No Answer	3.92 .05											12.86 .005			4.53 .03	8.70 .03
Strategy																
Algorithmic		5.51 .02		12.15 .007								8.49 .04	10.28 .001	3.94 .05		19.12 .0003
Alg/Reasoning	8.21 .004	18.24 < .0001	19.74 < .0001	41.02 < .0001	8.55 .004		4.29 .04	13.67 .003	14.87 .0001	20.26 <.0001	12.66 .0004	31.54 <.0001	38.87 <.0001	15.43 .0001	30.97 < .0001	44.84 < .0001
Random T & E	6.59 .01									4.57 .03						
Structural Error																
Misinterprets							7.37 .01									
Disregards given																
Disregards gen		3.98 .05														
Misapplies													4.02 .04			
Not generate		4.84 .03		10.14 .02												

Table 219 (continued)

Summary of Significant Findings: Problem Solved Correctly

	Moles				Gas Laws				Stoichiometry				Molarity			
Protocol Categories	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T	P1	P2	P3	T
*Evaluation							33 .002								209 .04	
*Comments about Solution	1022 .0001	962 .0002	522 .01	22.76 <.0001	676 .003	510 .02			648 .0004	648 .0001	227 .03	22.60 .0001	553 .02		435 .0004	13.77 .003
*Executive Errors	780 .02	770 .03			682 .0002	561 .002		9.40 .02								
*Problems Correct	X[i]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
*Questions Correct	406 .002	471 .02	234 .03	13.24 .004			14 .02						271 .001	78 .002	127 .005	19.23 .0002
*Question w/o Prompting	320 .0001	360 .0004	140 .0005	23.65 <.0001	307 .004			9.73 .02	283 .03	204 .001	62 .02	14.70 .002	279 .02	109 .02		10.17 .02
Structural Errors																
Section[h] 1 - 1	X	X	X	X	11.4 .02	X	X	X	32.92 <.0001	X	X	X	24.64 .0009	X	X	X
Section 1 - 2	X	X	X	X	29.75 <.0001	X	X	X	26.30 <.0001	X	X	X	39.49 <.0001	X	X	X
Section 2 - 1	X	X	X	X	X		X	X	X	12.40 .002	X	X	X	25.68 .0003	X	X
Section 2 - 2	X	X	X	X	X	29.76 <.0001	X	X	X	42.81 <.0001	X	X	X	13.36 .04	X	X
Section 3 - 1	X	X	X	X	X	X		X	X	X		X	X	X	20.17 .01	X
Section 3 - 2	X	X	X	X	X	X	19.96 .006	X	X	X		X	X	X	38.72 <.0001	X
Section 3 - 3	X	X	X	X	X	X		X	X	X	27.05 <.0001	X	X	X	30.29 <.0001	X

*Category sum

[a]Problem 1

[b]Problem 2

[c]Problem 3

[d]Sum of Problems 1, 2 & 3

[e]Statistic

[f]Probability level

[g]Sum of rereads and restates subcategories

[h]Section on supplementary coding sheet

[i]Not meaningful

Table 220

Interview Data Analyses: Moles - Problem 1
Problem Solved Correctly

Problems Correct	Systemmatic Approach			Arithmetic Approach			Nonsystemmatic Approach		
	0	1	Total	0	1	Total	0	1	Total
No	14[a]	21	35	22	13	35	27	8	35
	40.0[b]	60.0	47.3	62.9	37.1	47.3	77.1	22.9	47.3
	100.0[c]	35.0		75.9	28.9		40.9	100.0	
	18.9[d]	28.4		29.7	17.6		36.5	10.8	
Yes	0	39	39	7	32	39	39	0	39
	0	100.0	52.7	17.9	82.1	52.7	100.0	0	52.7
	0	65.0		24.1	71.1		59.1	0	
	0	52.7		9.5	43.2		52.7	0	
Total	14	60	74	29	45	74	66	8	74
	18.9	81.1	100.0	39.2	60.8	100.0	89.2	10.8	100.0
	Chi Square		16.72	Chi Square		13.78	Chi Square		7.76
	df		1	df		1	df		1
	Phi		.510	Phi		.460	Phi		.367
	Significance		<.0001	Significance		.0002	Significance		.005

[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage

Table 221

Interview Data Analyses: Moles - Problem 1
Problem Solved Correctly

Problems Correct	No Answer Given			Algorithmic Reasoning Strategy			Use of Random Trial and Error		
	0	1	Total	0	1	Total	0	1	Total
	30	5	35	33	2	35	26	9	35
	85.7	14.3	47.3	94.3	5.7	47.3	74.3	25.7	47.3
No	43.5	100.0		56.9	12.5		40.6	90.0	
	40.5	6.8		44.6	2.7		35.1	12.2	
	39	0	39	25	14	39	38	1	39
	100.0	0	52.7	64.1	35.9	52.7	97.4	2.6	52.7
Yes	56.5	0		43.1	87.5		59.4	10.0	
	52.7	0		33.8	18.9		51.4	1.4	
Total	69	5	74	58	16	74	64	10	74
	93.2	6.8	100.0	78.4	21.6	100.0	86.5	13.5	100.0
	Chi Square		3.92	Chi Square		8.21	Chi Square		6.59
	df		1	df		1	df		1
	Phi		.284	Phi		.366	Phi		.338
	Significance		.05	Significance		.004	Significance		.01

Table 222

Interview Data Analyses: Moles - Problem 1
Problem Solved Correctly

Problems Correct	Comments About Solution					Executive Errors		
	0	1	2	3	Total	0	1	Total
	16[a]	15	3	1	35	30	5	35
	45.7[b]	42.9	8.6	2.9	47.3	85.7	14.5	47.3
No	30.2[c]	88.2	100.0	100.0	(47.2)[e]	43.5	100.0	(40.3)
	21.6[d]	20.3	1.4	1.4		40.5	6.8	
	37	2	0	0	39	39	0	39
	94.9	5.1	0	0	52.7	100.0	0	52.7
Yes	69.8	11.8	0	0	(28.8)	56.5	0	(35.0)
	50.0	2.7	0	0		52.7	0	
Total	53	17	3	1	74	69	5	74
	71.6	23.0	4.1	1.4	100.0	93.2	6.8	100.0
		Mann-Whitney U		1022		Mann-Whitney U		780
		Wilcoxon Rank Sum W		1652		Wilcoxon Rank Sum W		1410
		Z		4.67		Z		2.43
		Significance		<.0001		Significance		.02

[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[e] Mean rank

Table 223

Interview Data Analyses: Moles - Problem 1
Problems Solved Correctly

Problems Correct	Questions Correct					
	2	3	4	5	6	Total
	3	5	9	8	10	35
	8.6	14.3	25.7	22.9	28.6	47.3
No	75.0	71.4	75.0	47.1	29.4	(29.6)
	4.1	6.8	12.2	10.8	13.5	
	1	2	3	9	24	39
	2.6	5.1	7.7	23.1	61.5	52.7
Yes	25.0	28.6	25.0	52.9	70.6	(44.6)
	1.4	2.7	4.1	12.2	32.4	
Total	4	7	12	17	34	74
	5.4	9.5	16.2	23.0	45.9	100.0

Mann-Whitney U	406
Wilcoxon Rank Sum W	1036
Z	-3.18
Significance	.002

Table 224

Interview Data Analyses: Moles - Problem 1
Problems Solved Correctly

Problems Correct	Questions Correct Without Prompting 0	1	2	3	4	5	6	Total
No	2	4	12	6	6	5	0	35
	5.7	11.4	34.3	17.1	17.1	14.3	0	47.3
	66.7	100.0	75.0	46.2	42.9	27.8	0	(27.2)
	2.7	5.4	16.2	8.1	8.1	6.8	0	
Yes	1	0	4	7	8	13	6	39
	2.6	0	10.3	17.9	20.5	33.3	15.4	52.7
	33.3	0	25.0	53.8	57.1	72.2	100.0	(46.8)
	1.4	0	5.4	9.5	10.8	17.6	8.1	
Total	3	4	16	13	14	18	6	74
	4.1	5.4	21.6	17.6	18.9	24.3	8.1	100.0

Mann-Whitney U	320
Wilcoxon Rank Sum W	950
Z	-3.99
Significance	.0001

Table 225

Interview Data Analyses: Moles - Problem 2
Problem Solved Correctly

Problems Correct	Arithmetic Approach			Algorithmic Strategy Only			Algorithmic Reasoning Strategy		
	0	1	Total	0	1	Total	0	1	Total
No	24	15	39	15	24	39	35	4	39
	61.5	38.5	52.7	38.5	61.5	52.7	89.7	10.3	52.7
	72.7	36.6		38.5	68.6		71.4	16.0	
	32.4	20.3		20.3	32.4		47.3	5.4	
Yes	9	26	35	24	11	35	14	21	35
	25.7	74.3	47.3	68.6	31.4	47.3	40.0	60.0	47.3
	27.3	63.4		61.5	31.4		28.6	84.0	
	12.2	35.1		32.4	14.9		18.9	28.4	
Total	33	41	74	39	35	74	49	25	74
	44.6	55.4	100.0	52.7	47.3	100.0	66.2	33.8	100.0
	Chi Square		8.19	Chi Square		5.55	Chi Square		18.24
	df		1	df		1	df		1
	Phi		.36	Phi		.30	Phi		.52
	Significance		.004	Significance		.02	Significance		<.0001

Table 226

Interview Data Analyses: Moles - Problem 2
Problem Solved Correctly

Problems Correct	Disregards Information Generated 0	1	Total	Needed Information Not Generated 0	1	Total
No	33	6	39	30	9	39
	84.6	15.4	52.7	76.9	23.1	52.7
	48.5	100.0		46.9	90.0	
	44.6	8.1		40.5	12.2	
Yes	35	0	35	34	1	35
	100.0	0	47.3	97.1	2.9	47.3
	51.5	0		53.1	10.0	
	47.3	0		45.9	1.4	
Total	68	6	74	64	10	74
	91.9	8.1	100.0	86.5	13.5	100.0
	Chi Square		3.98	Chi Square		4.84
	df		1	df		1
	Phi		.28	Phi		.29
	Significance		.05	Significance		.03

Table 227

Interview Data Analyses: Moles - Problem 2
Problem Solved Correctly

Problems Correct	Comments About Solution				Executive Errors		
	0	1	2	Total	0	1	Total
No	19	16	4	39	34	5	39
	48.7	41.0	10.3	52.7	87.2	12.8	52.7
	38.0	80.0	100.0	(44.7)	49.3	100.0	(39.7)
	25.7	21.6	5.4		45.9	6.8	
Yes	31	4	0	35	35	0	35
	88.6	11.4	0	47.3	100.0	0	47.3
	62.0	20.0	0	(29.5)	50.7	0	(35.0)
	41.9	5.4	0		47.3	0	
Total	50	20	4	74	69	5	74
	67.6	27.0	5.4	100.0	93.2	6.8	100.0

Mann-Whitney U	962	Mann-Whitney U	770
Wilcoxon Rank Sum W	1035	Wilcoxon Rank Sum W	1225
Z	3.70	Z	2.18
Significance	.0002	Significance	.03

Table 228

Interview Data Analyses: Moles - Problem 2 Problems Solved Correctly

Problems Correct	Questions Correct					
	2	3	4	5	6	Total
No	4	5	8	8	14	39
	10.3	12.8	20.5	20.5	35.9	52.7
	100.0	71.4	66.7	47.1	41.2	(32.1)
	5.4	6.8	10.8	10.8	18.9	
Yes	0	2	4	9	20	35
	0	5.7	33.3	25.7	57.1	47.3
	0	28.6	11.4	52.9	58.8	(43.5)
	0	2.7	5.4	12.2	27.0	
Total	4	7	12	17	34	74
	5.4	9.5	16.2	23.0	45.9	100.0

Mann-Whitney U	471
Wilcoxon Rank Sum W	1524
Z	-2.43
Significance	.02

Table 229

Interview Data Analyses: Moles - Problem 2
Problems Solved Correctly

Problems	Questions Correct Without Prompting							
Correct	0	1	2	3	4	5	6	Total
	3	4	12	5	8	6	1	39
	7.7	10.3	30.8	12.8	20.5	15.4	2.6	52.7
No	100.0	100.0	75.0	38.5	57.1	33.3	16.7	(29.2)
	4.1	5.4	16.2	6.8	10.8	8.1	1.4	
	0	0	4	8	6	12	5	35
	0	0	11.4	22.9	17.1	34.3	14.3	47.3
Yes	0	0	25.0	61.5	42.9	66.7	83.3	(46.7)
	0	0	5.4	10.8	8.1	16.2	6.8	
Total	3	4	16	13	14	18	35	74
	4.1	5.4	21.6	17.6	18.9	24.3	47.3	100.0

Mann-Whitney U	360
Wilcoxon Rank Sum W	1634
Z	-3.55
Significance	.0004

Table 230

Interview Data Analyses: Moles - Problem 3
Problem Solved Correctly

Problems Correct	Systemmatic Approach			Arithmetic Approach		
	0	1	Total	0	1	Total
	30	32	62	43	19	62
	48.4	51.6	83.8	69.4	30.6	83.8
No	100.0	72.7		95.6	65.5	
	40.5	43.2		58.1	25.7	
	0	12	12	2	10	12
	0	100.0	16.2	16.7	83.3	16.2
Yes	0	27.3		4.4	34.5	
	0	16.2		2.7	13.5	
Total	30	44	74	45	29	74
	40.5	59.5	100.0	60.8	39.2	100.0
	Chi Square	7.86		Chi Square	9.61	
	df	1		df	1	
	Phi	.36		Phi	.40	
	Significance	.005		Significance	.002	

Table 231

Interview Data Analyses: Moles - Problem 3
Problem Solved Correctly

Problems Correct	Algorithmic Reasoning Strategy 0	1	Total	Comments About Solution 0	1	2	Total
No	52	10	62	32	28	2	62
	83.9	16.1	83.8	51.6	45.2	3.2	83.8
	96.3	50.0		74.4	96.6	100.0	(39.9)
	70.3	13.5		43.2	37.8	2.7	
Yes	2	10	12	11	1	0	12
	16.7	83.3	16.2	91.7	8.3	0	16.2
	3.7	50.0		25.6	3.4	0	(25.0)
	2.7	13.5		14.9	1.4	0	
Total	54	20	74	43	29	2	74
	73.0	27.0	100.0	58.1	39.2	2.7	100.0

Chi Square	19.74
df	1
Phi	.56
Significance	< .0001

Mann-Whitney U	522
Wilcoxon Rank Sum W	300
Z	2.55
Significance	.01

Table 232

Interview Data Analyses: Moles - Problem 3
Problems Solved Correctly

Problems Correct	Questions Correct					
	2	3	4	5	6	Total
No	4	7	12	13	26	62
	6.5	11.3	19.4	21.0	41.9	83.8
	100.0	100.0	100.0	76.5	76.5	(35.3)
	5.4	9.5	16.2	17.6	35.1	
Yes	0	0	0	4	8	12
	0	0	0	33.3	66.7	16.2
	0	0	0	23.5	23.5	(49.0)
	0	0	0	5.4	10.8	
Total	4	7	12	17	34	74
	5.4	9.5	16.2	23.0	45.9	100.0

Mann-Whitney U	234
Wilcoxon Rank Sum W	588
Z	-2.15
Significance	.03

Table 233

Interview Data Analyses: Moles - Problem 3
Problems Solved Correctly

Problems Correct	Questions Correct Without Prompting							
	0	1	2	3	4	5	6	Total
No	3	4	16	13	12	8	6	62
	4.8	6.5	25.8	21.0	19.4	12.9	9.7	83.8
	100.0	100.0	100.0	100.0	85.7	44.4	100.0	(33.8)
	4.1	5.4	21.6	17.6	16.2	10.8	8.1	
Yes	0	0	0	0	2	10	0	12
	0	0	0	0	16.7	83.3	0	16.2
	0	0	0	0	14.3	55.6	0	(56.8)
	0	0	0	0	2.7	13.5	0	
Total	3	4	16	13	14	18	6	74
	4.1	5.4	21.6	17.6	18.9	24.3	8.1	100.0

Mann-Whitney U	140
Wilcoxon Rank Sum W	682
Z	-3.47
Significance	.0005

Table 234

Interview Data Analyses: Moles - Total Problem Solved Correctly

Problems Correct	Systemmatic Approach					Arithmetic Approach				
	0	1	2	3	Total	0	1	2	3	Total
0	6	4	7	10	27	14	5	5	3	27
	22.2	14.8	25.9	37.0	36.5	51.9	18.5	18.5	11.1	36.5
	85.7	50.0	33.3	26.3	(29.9)	60.9	50.0	27.8	13.0	(26.4)
	8.1	5.4	9.5	13.5		18.9	6.8	6.8	4.1	
1	1	3	7	5	16	5	3	6	2	16
	6.3	18.8	43.8	31.3	21.6	31.3	18.8	37.5	12.5	21.6
	14.3	37.5	33.3	13.2	(31.1)	21.7	30.0	33.3	8.7	(32.9)
	1.4	4.1	9.5	6.8		6.8	4.1	8.1	2.7	
2	0	1	7	15	23	4	1	7	11	23
	0	4.3	30.4	65.2	31.1	17.4	4.3	30.4	47.8	31.1
	0	12.5	33.3	39.5	(44.6)	17.4	10.0	38.9	47.8	(46.4)
	0	1.4	9.5	20.3		5.4	1.4	9.5	14.9	
3	0	0	0	8	8	0	1	0	7	8
	0	0	0	100.0	10.8	0	12.5	0	87.5	10.8
	0	0	0	21.1	(55.5)	0	10.0	0	30.4	(58.7)
	0	0	0	10.8		0	1.4	0	9.5	
Total	7	8	21	38	74	23	10	18	23	74
	9.5	10.8	28.4	51.4	100.0	31.1	13.5	24.3	31.1	100.0

KW Chi Square	15.37	KW Chi Square	21.29
df	9	df	9
Significance	.001	Significance	.0001

Table 235

Interview Data Analyses: Moles - Total Problem Solved Correctly

Problems Correct	Nonsystematic Approach					Algorithmic Strategy Only				
	0	1	2	3	Total	0	1	2	3	Total
0	15 55.6 28.8 20.3	7 25.9 53.8 9.5	3 11.1 50.0 4.1	2 7.4 66.7 2.7	27 36.5 (43.0)	6 22.2 28.6 8.1	5 18.5 27.8 6.8	8 29.6 40.0 10.8	8 29.6 53.3 10.8	27 36.5 (42.6)
1	10 62.5 19.2 13.5	2 12.5 15.4 2.7	3 18.8 50.0 4.1	1 6.3 33.3 1.4	16 21.6 (41.3)	1 6.3 4.8 1.4	5 31.3 27.8 6.8	6 37.5 30.0 8.1	4 25.0 26.7 5.4	16 21.6 (45.5)
2	19 82.6 36.5 25.7	4 17.4 30.8 5.4	0 0 0 0	0 0 0 0	23 31.1 (32.2)	8 34.8 38.1 10.8	7 30.4 38.9 9.5	5 21.7 25.0 6.8	3 13.0 20.0 4.1	23 31.1 (32.6)
3	8 100.0 15.4 10.8	0 0 0 0	0 0 0 0	0 0 0 0	8 10.8 (26.5)	6 75.0 28.6 8.1	1 12.5 5.6 1.4	1 12.5 5.0 1.4	0 0 0 0	8 10.8 (18.3)
Total	52 70.3	13 17.6	6 8.1	3 4.1	74 100.0	21 28.4	18 24.3	20 27.0	15 20.3	74 100.0

Nonsystematic Approach		Algorithmic Strategy Only	
KW Chi Square	8.99	KW Chi Square	12.15
df	9	df	9
Significance	.03	Significance	.007

Table 236

Interview Data Analyses: Moles - Total
Problem Solved Correctly

Problems Correct	Algorithmic Reasoning Strategy					Needed Information Not Generated			
	0	1	2	3	Total	0	1	2	Total
0	25	1	1	0	27	15	9	3	27
	92.6	3.7	3.7	0	36.5	55.6	33.3	11.1	36.5
	55.6	12.5	10.0	0	(25.3)	28.3	52.9	75.0	(43.7)
	33.8	1.4	1.4	0		20.3	12.2	4.1	
1	13	3	0	0	16	10	5	1	16
	81.3	18.8	0	0	21.6	62.5	31.3	6.3	21.6
	28.9	37.5	0	0	(28.0)	18.9	29.4	25.0	(40.8)
	17.6	4.1	0	0		13.5	6.8	1.4	
2	7	3	8	5	23	20	3	0	23
	30.4	13.0	34.8	21.7	31.1	87.0	13.0	0	31.1
	15.6	37.5	80.0	45.5	(48.8)	37.7	17.6	0	(31.6)
	9.5	4.1	10.8	6.8		27.0	4.1	0	
3	0	1	1	6	8	8	0	0	8
	0	12.5	12.5	75.0	10.8	100.0	0	0	10.8
	0	12.5	10.0	54.5	(65.3)	15.1	0	0	(27.0)
	0	1.4	1.4	8.1		10.8	0	0	
Total	45	8	10	11	74	53	17	5	74
	60.8	10.8	13.5	14.9	100.0	71.6	23.0	5.4	100.0

	Algorithmic Reasoning Strategy	Needed Information Not Generated
KW Chi Square	41.02	10.14
df	9	6
Significance	<.0001	.02

Table 237

Interview Data Analyses: Moles - Total Problem Solved Correctly

Problems Correct	Comments About Solution						
	0	1	2	3	4	5	Total
0	5	6	5	9	1	1	27
	18.5	22.2	18.5	33.3	3.7	3.7	36.5
	16.1	31.6	62.5	69.2	50.0	100.0	(49.3)
	6.8	8.1	6.8	12.2	1.4	1.4	
1	6	3	2	4	1	0	16
	37.5	18.8	12.5	25.0	6.3	0	21.6
	19.4	15.8	25.0	30.8	50.0	0	(41.3)
	8.1	4.1	2.7	5.4	1.4	0	
2	12	10	1	0	0	0	23
	52.2	43.5	4.3	0	0	0	31.1
	38.7	52.6	12.5	0	0	0	(28.5)
	16.2	13.5	1.4	0	0	0	
3	8	0	0	0	0	0	8
	100.0	0	0	0	0	0	10.8
	25.8	0	0	0	0	0	(16.0)
	10.8	0	0	0	0	0	
Total	31	19	8	13	2	1	74
	41.9	25.7	10.8	17.6	2.7	1.4	100.0

KW Chi Square 22.76
df 15
Significance < .0001

6

Table 238

Interview Data Analyses: Moles - Total Problems Solved Correctly

Problems Correct	Questions Correct					
	2	3	4	5	6	Total
	3	4	8	6	6	27
	11.1	14.8	29.6	22.2	22.2	36.5
0	75.0	57.1	66.7	35.3	17.6	(26.5)
	4.1	5.4	10.8	8.1	8.1	
	1	2	1	3	9	16
	6.3	12.5	6.3	18.8	56.3	21.6
1	25.0	28.6	8.3	17.6	26.5	(40.6)
	1.4	2.7	1.4	4.1	12.2	
	0	1	3	5	14	23
	0	4.3	13.0	21.7	60.9	31.1
2	0	14.3	25.0	29.4	41.2	(44.6)
	0	1.4	4.1	6.8	18.9	
	0	0	0	3	5	8
	0	0	0	37.5	62.5	10.8
3	0	0	0	17.6	14.7	(47.9)
	0	0	0	4.1	6.8	
Total	4	7	12	17	34	74
	5.4	9.5	16.2	23.0	45.9	100.0

KW Chi Square	13.24
df	12
Significance	.004

Table 239

Interview Data Analyses: Moles - Total Problems Solved Correctly

Problems Correct	Questions Correct Without Prompting							
	0	1	2	3	4	5	6	Total
0	2	4	10	4	5	2	0	27
	7.4	14.8	37.0	14.8	18.5	7.4	0	36.5
	66.7	100.0	62.5	30.8	35.7	11.1	0	(23.6)
	2.7	5.4	13.5	5.4	6.8	2.7	0	
1	1	0	4	3	3	4	1	16
	6.3	0	25.0	18.8	18.8	25.0	6.3	21.6
	33.3	0	25.0	23.1	21.4	22.2	16.7	(37.1)
	1.4	0	5.4	4.1	4.1	5.4	1.4	
2	0	0	2	6	5	5	5	23
	0	0	8.7	26.1	21.7	21.7	21.7	31.1
	0	0	12.5	46.2	35.7	27.8	83.3	(47.1)
	0	0	2.7	8.1	6.8	6.8	6.8	
3	0	0	0	0	1	7	0	8
	0	0	0	0	12.5	87.5	0	10.8
	0	0	0	0	7.1	38.9	0	(57.5)
	0	0	0	0	1.4	9.5	0	
Total	3	4	16	13	14	18	6	74
	4.1	5.4	21.6	17.6	18.9	24.3	8.1	100.0

KW Chi Square	23.65
df	18
Significance	< .0001

Table 240

Interview Data Analyses: Gas Laws - Problem 1
Problem Solved Correctly

Problem Correct	Algorithmic Reasoning Strategy			Comments about Solution			Executive Errors		
	0	1	Total	0	1	Total	0	1	Total
	27	8	35	21	14	35	23	12	35
	77.1	22.9	54.7	60.0	40.0	54.7	65.7	34.3	54.7
No	71.1	30.8		43.8	87.5	(37.3)	44.2	100.0	(37.5)
	42.2	12.5		32.8	21.9		35.9	18.8	
	11	18	29	27	2	29	29	0	29
	37.9	62.1	45.3	93.1	6.9	45.3	100.0	0	45.3
Yes	28.9	69.2		56.3	12.5	(26.7)	55.8	0	(26.5)
	17.2	28.1		42.2	3.1		45.3	0	
Total	38	26	64	48	16	64	52	12	64
	59.4	40.6	100.00	75.0	25.0	100.0	81.3	18.8	100.0
	Chi Square		8.55	Mann Whitney U		676	Mann Whitney U		682
	df		1	Wilcoxon Rank Sum W		774	Wilcoxon Rank Sum W		768
	Phi		.40	Z		3.02	Z		3.47
	Significance		.004	Significance		.003	Significance		.0005

Table 241

Interview Data Analyses: Gas Laws - Problem 1
Problem Solved Correctly

Problems	Questions Correct Without Prompting					
Correct	0	1	2	3	4	Total
	3	5	14	11	2	35
	8.6	14.3	40.0	31.4	5.7	54.7
No	100.0	62.5	73.7	42.3	25.0	(26.8)
	4.7	7.8	21.9	17.2	3.1	
	0	3	5	15	6	29
	0	10.3	17.2	51.7	20.7	45.3
Yes	0	37.5	26.3	57.7	75.0	(39.4)
	0	4.7	7.8	23.4	9.4	
	3	8	19	26	8	64
Total	4.7	12.5	29.7	40.6	12.5	100.0

Mann-Whitney U	307
Wilcoxon Rank Sum W	1143
Z	-2.84
Significance	.004

Table 242

Interview Data Analyses: Gas Laws - Problem 1
Problem Solved Correctly

Problem Correct	Structural Error 1						Structural Error 2				
	0	1	2	3	4	Total	0	1	2	3	Total
	1[a]	11	8	1	14	35	5	1	17	12	35
	2.9[b]	31.4	22.9	2.9	40.0	54.7	14.3	2.9	48.6	34.3	54.7
No	100.0[c]	57.9	100.0	100.0	40.0		100.0	100.0	100.0	29.3	
	1.6[d]	17.2	12.5	1.6	21.9		7.8	1.6	26.6	18.8	
	0	8	0	0	21	29	0	0	0	29	29
	0	27.6	0	0	72.4	45.3	0	0	0	100.0	45.3
Yes	0	42.1	0	0	60.0		0	0	0	70.7	
	0	12.5	0	0	32.8		0	0	0	45.3	
Total	1	19	8	1	35	64	5	1	17	41	64
	1.6	29.7	12.5	1.6	54.7	100.0	7.8	1.6	26.6	64.1	100.0

	Structural Error 1	Structural Error 2
Chi Square	11.4	29.75
df	4	3
V	.42[f]	.68
Significance	.02	<.0001

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[a] Count
[b] Row percentage
[c] Column percentage
[d] Total percentage
[f] Cramer's V

Table 243

Interview Data Analyses: Gas Laws - Problem 2
Problem Solved Correctly

Problems Correct	Reading/Organizing Skills						Rereading/Stating Problem			
	0	1	2	3	4	Total	0	1	2	Total
No	5	24	16	2	0	47	30	17	0	47
	10.6	51.1	34.0	4.3	0	73.4	63.8	36.2	0	73.4
	55.6	68.6	94.1	100.0	0	(35.0)	65.2	100.0	0	(34.9)
	7.8	37.5	25.0	3.1	0		46.9	26.6	0	
Yes	4	11	1	0	1	17	16	0	1	17
	23.5	64.7	5.9	0	5.9	26.6	94.1	0	5.9	26.6
	44.4	31.4	5.9	0	100.0	(25.5)	34.8	0	100.0	(25.9)
	6.3	17.2	1.6	0	1.6		25.0	0	1.6	
Total	9	35	17	2	1	64	46	17	1	64
	14.1	54.7	26.6	3.1	1.6	100.0	71.9	26.6	1.6	100.0

Mann-Whitney U	518	Mann-Whitney U	512
Wilcoxon Rank Sum W	434	Wilcoxon Rank Sum W	440
Z	1.99	Z	2.19
Significance	.05	Significance	.03

Table 244

Interview Data Analyses: Gas Laws - Problem 2
Problem Solved Correctly

Problem Correct	Comments about Solution				Executive Errors		
	0	1	2	3	0	1	2
	34	12	1	47	28	19	47
	72.3	25.5	2.1	73.4	59.6	40.4	73.4
No	66.7	100.0	100.0	(34.9)	62.2	100.0	(35.9)
	53.1	18.8	1.6		43.8	29.7	
	17	0	0	17	17	0	17
	100.0	0	0	26.6	100.0	0	26.6
Yes	33.3	0	0	(26.0)	37.8	0	(23.0)
	26.6	0	0		26.6	0	
Total	51	12	1	64	45	19	64
	79.7	18.8	1.6	100.0	70.3	29.7	100.0

Mann-Whitney U	510	Mann-Whitney U	561
Wilcoxon Rank Sum W	442	Wilcoxon Rank Sum W	391
Z	2.40	Z	3.10
Significance	.02	Significance	.002

Table 245

Interview Data Analyses: Gas Laws - Problem 2
Problem Solved Correctly

Problems Correct	Structural Error 2						
	0	1	2	3	4	5	Total
No	5	3	2	20	6	11	47
	10.6	6.4	4.3	42.6	12.8	23.4	73.4
	100.0	100.0	100.0	100.0	100.0	39.3	
	7.8	4.7	3.1	31.3	9.4	17.2	
Yes	0	0	0	0	0	17	17
	0	0	0	0	0	100.0	26.6
	0	0	0	0	0	60.7	
	0	0	0	0	0	26.6	
Total	5	3	2	20	6	28	64
	7.8	4.7	3.1	31.3	9.4	43.8	100.0

Chi Square	29.76
df	5
V	.68
Significance	<.0001

Table 246

Interview Data Analyses: Gas Laws - Problem 3
Problem Solved Correctly

Problems Correct	Algorithmic Reasoning Strategy			Misinterprets Problem			Evaluation Sum		
	0	1	Total	0	1	Total	0	1	Total
No	52	10	62	61	1	62	60	2	62
	83.9	16.1	96.9	98.4	1.6	96.9	96.8	3.2	96.9
	100.0	83.3		96.8	100.0		98.4	66.7	(32.0)
	81.3	15.6		95.3	1.6		93.8	3.1	
Yes	0	2	2	2	0	2	1	1	2
	0	100.0	3.1	100.0	0	3.1	50.0	50.0	3.1
	0	16.7		3.2	0		1.6	33.3	(47.0)
	0	3.1		3.1	0		1.6	1.6	
Total	52	12	64	63	1	64	61	3	64
	81.3	18.8	100.0	98.4	1.6	100.0	95.3	4.7	100.0

Chi Square	4.29	Chi Square	7.37	Mann-Whitney U	33
df	1	df	1	Wilcoxon Rank Sum W	94
Phi	.37	Phi	.02	Z	-3.06
Significance	.04	Significance	.007	Significance	.002

Table 248

Interview Data Analyses: Gas Laws - Problem 3
Problem Solved Correctly

Problems Correct	Questions Correct 2	 3	 4	 Total
	5	43	14	62
	8.1	69.4	22.6	96.9
No	100.0	100.0	87.5	(31.7)
	7.8	67.2	21.9	
	0	0	2	2
	0	0	100.0	3.1
Yes	0	0	12.5	(56.5)
	0	0	3.1	
Total	5	43	16	64
	7.8	67.2	25.0	100.0

Mann-Whitney U	14
Wilcoxon Rank Sum W	113
Z	-2.24
Significance	.02

Table 249

Interview Data Analyses: Gas Laws - Problem 3
Problem Solved Correctly

Problems Correct	Structural Error 2								
	0	1	2	3	4	7	8	9	Total
No	26	1	9	1	13	4	3	5	62
	41.9	1.6	14.5	1.6	21.0	6.5	4.8	8.1	96.9
	100.0	100.0	100.0	100.0	100.0	66.7	100.0	100.0	
	40.6	1.6	14.1	1.6	20.3	6.3	4.7	7.8	
Yes	0	0	0	0	0	2	0	0	2
	0	0	0	0	0	100.0	0	0	3.1
	0	0	0	0	0	33.3	0	0	
	0	0	0	0	0	3.1	0	0	
Total	26	1	9	1	13	6	3	5	64
	40.6	1.6	14.1	1.6	20.3	9.4	4.7	7.8	100.0

Chi Square	19.96
df	7
V	.59
Significance	.006

Table 250

Interview Data Analyses: Gas Laws - Total Problem Solved Correctly

Problems Correct	Use of Mneumonic Notation					Algorithmic Reasoning Strategy				
	0	1	2	3	Total	0	1	2	3	Total
0	6	3	13	10	32	19	7	4	2	32
	18.8	9.4	40.6	31.3	50.0	59.4	21.9	12.5	6.3	50.0
	85.7	37.5	46.4	47.6	(29.0)	63.3	70.0	25.0	25.0	(26.8)
	9.4	4.7	20.3	15.6		29.7	10.9	6.3	3.1	
1	0	2	11	5	18	9	1	7	1	18
	0	11.1	61.1	27.8	28.1	50.0	5.6	38.9	5.6	28.1
	0	25.0	39.3	23.8	(39.0)	30.0	10.0	43.8	12.5	(31.9)
	0	3.1	17.2	7.8		14.1	1.6	10.9	1.6	
2	1	2	4	5	12	2	2	5	3	12
	8.3	16.7	33.3	41.7	18.8	16.7	16.7	41.7	25.0	18.8
	14.3	25.0	14.3	23.8	(33.7)	6.7	20.0	31.3	37.5	(43.8)
	1.6	3.1	6.3	7.8		3.1	3.1	7.8	4.7	
3	0	1	0	1	2	0	0	0	2	2
	0	50.0	0	50.0	3.1	0	0	0	100.0	3.1
	0	12.5	0	4.8	(23.0)	0	0	0	25.0	(60.5)
	0	1.6	0	1.6		0	0	0	3.1	
Total	7	8	28	21	64	30	10	16	8	64
	10.9	12.5	43.8	32.8	100.0	46.9	15.6	25.0	12.5	100.0

	Use of Mneumonic Notation		Algorithmic Reasoning Strategy
KW Chi Square	8.01	KW Chi Square	13.67
df	5	df	9
Significance	.05	Significance	.003

Table 251

Interview Data Analyses: Gas Laws - Total Problem Solved Correctly

Problems Correct	Executive Errors					Questions Correct Without Prompting					
	0	1	2	3	Total	0	1	2	3	4	Total
0	15	10	5	2	32	3	5	12	11	1	32
	46.9	31.3	15.6	6.3	50.0	9.4	15.6	37.5	34.4	3.1	50.0
	39.5	52.6	100.0	100.0	(37.5)	100.0	62.5	63.2	42.3	12.5	(26.1)
	23.4	15.6	7.8	3.1		4.7	7.8	18.8	17.2	1.6	
1	10	8	0	0	18	0	1	5	8	4	18
	55.6	44.4	0	0	28.1	0	5.6	27.8	44.4	22.2	28.1
	26.3	42.1	0	0	(32.2)	0	12.5	26.3	30.8	50.0	(39.0)
	15.6	12.5	0	0		0	1.6	7.8	12.5	6.3	
2	11	1	0	0	12	0	2	2	6	2	12
	91.7	8.3	0	0	18.8	0	16.7	16.7	50.0	16.7	18.8
	28.9	5.3	0	0	(21.9)	0	25.0	10.5	23.1	25.0	(36.6)
	17.2	1.6	0	0		0	3.1	3.1	9.4	3.1	
3	2	0	0	0	2	0	0	0	1	1	2
	100.0	0	0	0	3.1	0	0	0	50.0	50.0	3.1
	5.3	0	0	0	(19.5)	0	0	0	3.8	12.5	(52.0)
	3.1	0	0	0		0	0	0	1.6	1.6	
Total	38	19	5	2	64	3	8	19	26	8	64
	59.4	29.7	7.8	3.1	100.0	4.7	12.5	29.7	40.6	12.5	100.0

Executive Errors		Questions Correct Without Prompting	
KW Chi Square	9.40	KW Chi Square	9.73
df	9	df	12
Significance	.02	Significance	.02

Table 252

Interview Data Analyses: Stoichiometry - Problem 1
Problem Solved Correctly

Problems Correct	Systemmatic Approach			Algorithmic Reasoning Strategy			Comments About Solution			
	0	1	Total	0	1	Total	0	1	Total	
No	18	30	48	41	7	48	17	30	1	48
	37.5	62.5	72.7	85.4	14.6	72.7	35.4	62.5	2.1	72.7
	94.7	63.8		87.2	36.8		51.5	96.8	50.0	(38.0)
	27.3	45.5		62.1	10.6		25.8	45.5	1.5	
Yes	1	17	18	6	12	18	16	1	1	18
	5.6	94.4	27.3	33.3	66.7	27.3	88.9	5.6	5.6	27.3
	5.3	36.2		12.8	63.2		48.5	3.2	50.0	(21.5)
	1.5	25.8		9.1	18.2		24.2	1.5	1.5	
Total	19	47	66	47	19	66	33	31	2	66
	28.8	71.2	100.0	71.2	28.8	100.0	50.0	47.0	3.0	100.0

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Chi Square	5.05	Chi Square	14.87	Mann-Whitney U	648
df	1	df	1	Wilcoxon Rank Sum W	386
Phi	.31	Phi	.51	Z	3.54
Significance	.02	Significance	.0001	Significance	.0004

Table 253

Interview Data Analyses: Stoichiometry - Problem 1
Problem Solved Correctly

Problems Correct	Questions Correct Without Prompting					
	0	1	2	3	4	Total
No	2	10	15	19	2	48
	4.2	20.8	31.3	39.6	4.2	72.7
	50.0	100.0	78.9	76.0	25.0	(30.4)
	3.0	15.2	22.7	28.8	3.0	
Yes	2	0	4	6	6	18
	11.1	0	22.2	33.3	33.3	27.3
	50.0	0	21.1	24.0	75.0	(41.8)
	3.0	0	6.1	9.1	9.1	
Total	4	10	19	25	8	66
	6.1	15.2	28.8	37.9	12.1	100.0

Mann-Whitney U	283
Wilcoxon Rank Sum W	752
Z	-2.24
Significance	.03

Table 254

Interview Data Analyses: Stoichiometry - Problem 1
Problem Solved Correctly

Problems Correct	Structural Error - 2					Structural Error - 1				
	0	1	2	3	Total	0	1	2	3	Total
	9	14	4	21	48	2	7	11	28	48
	18.8	29.2	8.3	43.8	72.7	4.2	14.6	22.9	58.3	72.7
No	100.0	43.8	100.0	100.0		100.0	30.4	84.6	100.0	
	13.6	21.2	6.1	31.8		3.0	10.6	16.7	42.4	
	0	18	0	0	18	0	16	2	0	18
	0	100.0	0	0	27.3	0	88.9	11.1	0	27.3
Yes	0	56.3	0	0		0	69.6	15.4	0	
	0	27.3	0	0		0	24.2	3.0	0	
Total	9	32	4	21	66	2	23	13	28	66
	13.6	48.5	6.1	31.8	100.0	3.0	34.8	19.7	42.4	100.0

Structural Error - 2		Structural Error - 1	
Chi Square	26.30	Chi Square	32.92
df	3	df	3
V	.63	V	.71
Significance	< .0001	Significance	<.0001

Table 255

Interview Data Analyses: Stoichiometry - Problem 2
Problem Solved Correctly

Problems Correct	Rereading/Stating Problem				Systemmatic Approach			Algorithmic Reasoning Strategy		
	0	1	2	Total	0	1	Total	0	1	Total
No	24	24	1	49	20	29	49	42	7	49
	49.0	49.0	2.0	74.2	40.8	59.2	74.2	85.7	14.3	74.2
	64.9	85.7	100.0	(35.9)	100.0	63.0		91.3	35.0	
	36.4	36.4	1.5		30.3	43.9		63.6	10.6	
Yes	13	4	0	17	0	17	17	4	13	17
	76.5	23.5	0	25.8	0	100.0	25.8	23.5	76.5	25.8
	35.1	14.3	0	(26.6)	0	37.0		8.7	65.0	
	19.7	6.1	0		0	25.8		6.1	19.7	
Total	37	28	1	66	20	46	66	46	20	66
	56.1	42.4	1.5	100.0	30.3	69.7	100.0	69.7	30.3	100.0
	Mann-Whitney U		533		Chi Square		8.12	Chi Square		20.26
	df		453		df		1	df		1
	Phi		1.97		V		.39	Phi		.59
	Significance		.05		Significance		.004	Significance		<.0001

Table 256

Interview Data Analyses: Stoichiometry - Problem 2
Problem Solved Correctly

Problems Correct	Use of Random Trial and Error			Comments About Solution				Structural Error - 2				
	0	1	Total	0	1	2	Total	0	1	2	3	Total
No	35	14	49	19	28	2	49	13	6	12	18	49
	71.4	28.6	74.2	38.8	57.1	4.1	74.2	26.5	12.2	24.5	36.7	74.2
	67.3	100.0		54.3	96.6	100.0	(38.2)	100.0	26.1	100.0	100.0	
	53.0	21.2		28.8	42.4	3.0		19.7	9.1	18.2	27.3	
Yes	17	0	17	6	1	0	17	0	17	0	0	17
	100.0	0	25.8	94.1	5.9	0	25.8	0	100.0	0	0	25.8
	32.7	0		45.7	3.4	0	(19.9)	0	73.9	0	0	
	25.8	0		24.2	1.5	0		0	25.8	0	0	
Total	52	14	66	35	29	2	66	13	23	12	18	66
	78.8	21.2	100.0	53.0	43.9	3.0	100.0	19.7	34.8	18.2	27.3	100.0

Use of Random Trial and Error		Comments About Solution		Structural Error - 2	
Chi Square	4.57	Mann-Whitney U	648	Chi Square	42.81
df	1	Wilcoxon Rank Sum W	338	df	3
Phi	.30	Z	3.88	V	.80
Significance	.03	Significance	.0001	Significance	< .0001

Table 257

Interview Data Anlyses: Stoichiometry - Problem 2
Problem Solved Correctly

Problems Correct	Structural Error - 1			
	0	1	2	Total
No	2	19	28	49
	4.1	38.8	57.1	74.2
	100.0	55.9	93.3	
	3.0	28.8	42.4	
Yes	0	15	2	17
	0	88.2	11.8	25.8
	0	44.1	6.7	
	0	22.7	3.0	
Total	2	34	30	66
	3.0	51.5	45.5	100.0

Chi Square	12.40
df	2
V	.43
Significance	.002

Table 258

Interview Data Analyses: Stoichiometry - Problem 2
Problem Solved Correctly

Problems Correct	Questions Correct Without Prompting					
	0	1	2	3	4	Total
	4	10	16	15	4	49
	8.2	20.4	32.7	30.6	8.2	74.2
No	100.0	100.0	84.2	60.0	50.0	(29.2)
	6.1	15.2	24.2	22.7	6.1	
	0	0	3	10	4	17
	0	0	17.6	58.8	23.5	25.8
Yes	0	0	15.8	40.0	50.0	(46.0)
	0	0	4.5	15.2	6.1	
Total	4	10	19	25	8	66
	6.1	15.2	28.8	37.9	12.1	100.0

Mann-Whitney U	204
Wilcoxon Rank Sum W	782
Z	-3.25
Significance	.001

Table 259

Interview Data Analyses: Stoichiometry - Problem 3
Problem Solved Correctly

Problems Correct	Systemmatic Approach 0	Systemmatic Approach 1	Systemmatic Approach Total	Algorithmic Reasoning Strategy 0	Algorithmic Reasoning Strategy 1	Algorithmic Reasoning Strategy Total	Comments About Solution 0	Comments About Solution 1	Comments About Solution Total
	34	27	61	55	6	61	19	42	61
	55.7	44.3	92.4	90.2	9.8	92.4	31.1	68.9	92.4
No	100.0	84.4		98.2	60.0		82.6	97.7	(34.7)
	51.5	40.9		83.3	9.1		28.8	63.6	
	0	5	5	1	4	5	4	1	5
	0	100.0	7.6	20.0	80.0	7.6	80.0	20.0	7.6
Yes	0	15.6		1.8	40.0		17.4	2.3	(18.6)
	0	7.6		1.5	6.1		6.1	1.5	
Total	34	32	66	56	10	66	23	43	66
	51.5	48.5	100.0	84.8	15.2	100.0	34.8	65.2	100.0

Systemmatic Approach		Algorithmic Reasoning Strategy		Comments About Solution	
Chi Square	3.73	Chi Square	12.66	Mann-Whitney U	227
df	1	df	1	Wilcoxon Rank Sum W	93
Phi	.29	Phi	.52	Z	.07
Significance	.05	Significance	.0004	Significance	.03

Table 260

Interview Data Analyses: Stoichiometry - Problem 3
Problem Solved Correctly

Problems Correct	Questions Correct Without Prompting					
	0	1	2	3	4	Total
	4	10	18	24	5	61
	6.6	16.4	29.5	39.3	8.2	92.4
No	100.0	100.0	94.7	96.0	62.5	(32.0)
	6.1	15.2	27.3	36.4	7.6	
	0	0	1	1	3	5
	0	0	20.0	20.0	60.0	7.6
Yes	0	0	5.3	4.0	37.5	(51.5)
	0	0	1.5	1.5	4.5	
Total	4	10	19	25	8	66
	6.1	15.2	28.8	37.9	12.1	100.0

Mann-Whitney U	62
Wilcoxon Rank Sum W	257
Z	-2.28
Significance	.02

Table 261

Interview Data Analyses: Stoichiometry - Problem 3
Problem Solved Correctly

Problems Correct	Structural Error - 3				
	0	1	2	3	Total
No	38 62.3 100.0 57.6	6 9.8 54.5 9.1	10 16.4 100.0 15.2	7 11.5 100.0 10.6	61 92.4
Yes	0 0 0 0	5 100.0 45.5 7.6	0 0 0 0	0 0 0 0	5 7.6
Total	38 57.6	11 16.7	10 15.2	7 10.6	66 100.0

Chi Square	27.05
df	3
V	.64
Significance	$< .0001$

Table 262

Interview Data Analyses: Stoichiometry - Total
Problem Solved Correctly

Problems Correct	Systematic Approach					No Answer Given				
	0	1	2	3	Total	0	1	2	3	Total
0	14	8	6	12	40	25	7	4	4	40
	35.0	20.0	15.0	30.0	60.6	62.5	17.5	10.0	10.0	60.6
	93.3	100.0	50.0	38.7	(26.4)	53.2	70.0	100.0	80.0	(39.2)
	21.2	12.1	9.1	18.2		37.9	10.6	6.1	6.1	
1	1	0	4	11	16	14	1	0	1	16
	6.3	0	25.0	68.8	24.2	87.5	6.3	0	6.3	24.2
	6.7	0	33.3	35.5	(42.9)	29.8	10.0	0	20.0	(26.8)
	1.5	0	6.1	16.7		21.2	1.5	0	1.5	
2	0	0	2	4	6	4	2	0	0	6
	0	0	33.3	66.7	9.1	66.7	33.3	0	0	9.1
	0	0	16.7	12.9	(43.8)	8.5	20.0	0	0	(21.5)
	0	0	3.0	6.1		6.1	3.0	0	0	
3	0	0	0	4	4	4	0	0	0	4
	0	0	0	100.0	6.1	100.0	0	0	0	6.1
	0	0	0	12.9	(51.0)	8.5	0	0	0	(21.5)
	0	0	0	6.1		6.1	0	0	0	
Total	15	8	12	31	66	47	10	4	5	66
	22.7	12.1	18.2	47.0	100.0	71.2	15.2	6.1	7.6	100.0

Systematic Approach		No Answer Given	
KW Chi Square	16.38	KW Chi Square	12.86
df	9	df	9
Significance	.001	Significance	.005

Table 263

Interview Data Analyses: Stoichiometry - Total Problem Solved Correctly

Problems Correct	Algorithmic Strategy Only					Comments About Solution					
	0	1	2	3	Total	0	1	2	3	4	Total
0	16 40.0 53.3 24.2	11 27.5 78.6 16.7	6 15.0 50.0 9.1	7 17.5 70.0 10.6	40 60.6 (34.8)	3 7.5 25.0 4.5	8 20.0 40.0 12.1	8 20.0 66.7 12.1	21 52.5 100.0 31.8	0 0 0 0	40 60.6 (41.6)
1	5 31.3 16.7 7.6	3 18.8 21.4 4.5	5 31.3 41.7 7.6	3 18.8 30.0 4.5	16 24.2 (39.2)	3 18.8 25.0 4.5	8 50.0 40.0 12.1	4 25.0 33.3 6.1	0 0 0 0	1 6.3 100.0 1.5	16 24.2 (26.2)
2	5 83.3 16.7 7.6	0 0 0 0	1 16.7 8.3 1.5	0 0 0 0	6 9.1 (21.3)	3 50.0 25.0 4.5	3 50.0 15.0 4.5	0 0 0 0	0 0 0 0	0 0 0 0	6 9.1 (14.5)
3	4 100.0 13.3 6.1	0 0 0 0	0 0 0 0	0 0 0 0	4 6.1 (15.5)	3 75.0 25.0 4.5	1 25.0 5.0 1.5	0 0 0 0	0 0 0 0	0 0 0 0	4 6.1 (10.5)
Total	30 45.5	14 21.2	12 18.2	10 15.2	66 100.0	12 18.2	20 30.3	12 18.2	21 31.8	1 1.5	66 100.0

KW Chi Square	8.49
df	9
Significance	.04

KW Chi Square	22.60
df	6
Significance	.0001

Table 264

Interview Data Analyses: Stoichiometry - Total Problem Solved Correctly

Problems Correct	Questions Correct Without Prompting						Algorithmic Reasoning Strategy				
	0	1	2	3	4	Total	0	1	2	3	Total
0	2	10	15	12	1	40	36	1	3	0	40
	5.0	25.0	37.5	30.0	2.5	60.6	90.0	2.5	7.5	0	60.6
	50.0	100.0	78.9	48.0	12.5	(26.9)	80.0	33.3	37.5	0	(25.8)
	3.0	15.2	22.7	18.2	1.5		54.5	1.5	4.5	0	
1	2	0	1	9	4	16	8	2	3	3	16
	12.5	0	6.3	56.3	25.0	24.2	50.0	12.5	18.8	18.8	24.2
	50.0	0	5.3	36.0	50.0	(43.3)	17.8	66.7	37.5	30.0	(38.8)
	3.0	0	1.5	13.6	6.1		12.1	3.0	4.5	4.5	
2	0	0	2	4	0	6	1	0	1	4	6
	0	0	33.3	66.7	0	9.1	16.7	0	16.7	66.7	9.1
	0	0	10.5	16.0	0	(38.7)	2.2	0	12.5	40.0	(53.6)
	0	0	3.0	6.1	0		1.5	0	1.5	6.1	
3	0	0	1	0	3	4	0	0	1	3	4
	0	0	25.0	0	75.0	6.1	0	0	25.0	75.0	6.1
	0	0	5.3	0	37.5	(52.9)	0	0	12.5	30.0	(59.3)
	0	0	1.5	0	4.5		0	0	1.5	4.5	
Total	4	10	19	25	8	66	45	3	8	10	66
	6.1	15.2	28.8	37.9	12.1	100.0	68.2	4.5	12.1	15.2	100.0

	Questions Correct Without Prompting		Algorithmic Reasoning Strategy
KW Chi Square	14.70	KW Chi Square	31.54
df	9	df	9
Significance	.002	Significance	<.0001

Table 265

Interview Data Analyses: Molarity - Problem 1
Problem Solved Correctly

Problems Correct	Systemmatic Approach			Arithmetic Approach			Algorithmic Strategy Only		
	0	1	Total	0	1	Total	0	1	Total
No	15	30	45	23	22	45	19	26	45
	33.3	66.7	70.3	51.1	48.9	70.3	42.2	57.8	70.3
	100.0	61.2		85.2	59.5		52.8	92.9	
	23.4	46.9		35.9	34.4		29.7	40.6	
Yes	0	19	19	4	15	19	17	2	19
	0	100.0	29.7	21.1	78.9	29.7	89.5	10.5	29.7
	0	38.8		14.8	40.5		47.2	7.1	
	0	29.7		6.3	23.4		26.6	3.1	
Total	15	49	64	27	37	64	36	28	64
	23.4	76.6	100.0	42.2	57.8	100.0	56.3	43.8	100.0
	Chi Square	6.52		Chi Square	3.79		Chi Square	10.28	
	df	1		df	1		df	1	
	Phi	.36		Phi	.28		Phi	.43	
	Significance	.01		Significance	.05		Significance	.001	

Table 266

Interview Data Analyses: Molarity - Problem 1
Problem Solved Correctly

Problems Correct	Algorithmic Reasoning Strategy			Misapplies Information Generated			Comments About Solution		
	0	1	Total	0	1	Total	0	1	Total
	42	3	45	34	11	45	27	18	45
	93.3	6.7	70.3	75.6	24.4	70.3	60.0	40.0	70.3
No	95.5	15.0		64.2	100.0		61.4	90.0	(35.3)
	65.6	4.7		53.1	17.2		42.2	28.1	
	2	17	19	19	0	19	17	2	19
	10.5	89.5	29.7	100.0	0	29.7	89.5	10.5	29.7
Yes	4.5	85.0		35.8	0		38.6	10.0	(25.9)
	3.1	26.6		29.7	0		26.6	3.1	
Total	44	20	64	53	11	64	44	20	64
	68.8	31.3	100.0	82.8	17.2	100.0	68.8	31.3	100.0
	Chi Square		38.87	Chi Square		4.02	Mann-Whitney U		553
	df		1	df		1	Wilcoxon Rank Sum W		491
	Phi		.82	Phi		.30	Z		2.30
	Significance		<.0001	Significance		.04	Significance		.02

Table 267

Interview Data Analyses: Molarity - Problem 1
Problem Solved Correctly

Problems Correct	Questions Correct					Questions Correct Without Prompting						
	2	3	4	5	Total	0	1	2	3	4	5	Total
	5	24	10	6	45	3	7	17	12	4	2	45
	11.1	53.3	22.2	13.3	70.3	6.7	15.6	37.8	26.7	8.9	4.4	70.3
No	83.3	96.0	45.5	54.5	(27.8)	100.0	100.0	68.0	75.0	50.0	40.0	(29.2)
	7.8	37.5	15.6	9.4		4.7	10.9	26.6	18.8	6.3	3.1	
	1	1	12	5	19	0	0	8	4	4	3	19
	5.3	5.3	63.2	26.3	29.7	0	0	42.1	21.1	21.1	15.8	29.7
Yes	16.7	4.0	54.5	45.5	(43.6)	0	0	32.0	25.0	50.0	60.0	(40.3)
	1.6	1.6	18.8	7.8		0	0	12.5	6.3	6.3	4.7	
Total	6	25	22	11	64	3	7	25	16	8	5	64
	9.4	39.1	34.4	17.2	100.0	4.7	10.9	39.1	25.0	12.5	7.8	100.0

Mann-Whitney U	217	Mann-Whitney U	279
Wilcoxon Rank Sum W	827	Wilcoxon Rank Sum W	766
Z	-3.26	Z	-2.27
Significance	.001	Significance	.02

Table 268

Interview Data Analyses: Molarity - Problem 1
Problem Solved Correctly

Problems Correct	Structural Error - 1								
	0	1	3	4	6	7	8	9	Total
No	7	8	4	1	2	2	8	13	45
	15.6	17.8	8.9	2.2	4.4	4.4	17.8	28.9	70.3
	100.0	100.0	100.0	100.0	100.0	66.7	100.0	41.9	
	10.9	12.5	6.3	1.6	3.1	3.1	12.5	20.3	
Yes	0	0	0	0	0	1	0	18	19
	0	0	0	0	0	5.3	0	94.7	29.7
	0	0	0	0	0	33.3	0	58.1	
	0	0	0	0	0	1.6	0	28.1	
Total	7	8	4	1	2	3	8	31	64
	10.9	12.5	6.3	1.6	3.1	4.7	12.5	48.4	100.0

Chi Square	24.64
df	7
V	.62
Significance	.0009

Table 269

Interview Data Analyses: Molarity - Problem 1
Problem Solved Correctly

Problems Correct	Structural Error - 2							
	0	1	2	6	7	8	9	Total
No	10	2	7	14	4	7	1	45
	22.2	4.4	15.6	31.1	8.9	15.6	2.2	70.3
	100.0	100.0	100.0	100.0	100.0	26.9	100.0	
	15.6	3.1	10.9	21.9	6.3	10.9	1.6	
Yes	0	0	0	0	0	19	0	19
	0	0	0	0	0	100.0	0	29.7
	0	0	0	0	0	73.1	0	
	0	0	0	0	0	29.7	0	
Total	10	2	7	14	4	26	1	64
	15.6	3.1	10.9	21.9	6.3	40.6	1.6	100.0

Chi Square	39.49
df	6
V	.78
Significance	<.0001

Table 270

Interview Data Analyses: Molarity - Problem 2
Problem Solved Correctly

Problems Correct	Algorithmic Strategy Only			Algorithmic Reasoning Strategy		
	0	1	Total	0	1	Total
No	24	32	56	47	9	56
	42.9	57.1	87.5	83.9	16.1	87.5
	77.4	97.0		97.9	56.3	
	37.5	50.0		73.4	14.1	
Yes	7	1	8	1	7	8
	87.5	12.5	12.5	12.5	87.5	12.5
	22.6	3.0		2.1	43.8	
	10.9	1.6		1.6	10.9	
Total	31	33	64	48	16	64
	48.4	51.6	100.0	75.0	25.0	100.0
	Chi Square		3.94	Chi Square		15.43
	df		1	df		1
	Phi		.29	Phi		.54
	Significance		.05	Significance		.0001

Table 271

Interview Data Analyses: Molarity - Problem 2
Problem Solved Correctly

Problems Correct	Questions Correct					Questions Correct Without Prompting						
	2	3	4	5	Total	0	1	2	3	4	5	Total
	6	25	18	7	56	3	7	23	14	7	2	56
	10.7	44.6	32.1	12.5	87.5	5.4	12.5	41.1	25.0	12.5	3.6	87.5
No	100.0	100.0	81.8	63.6	(29.9)	100.0	100.0	92.0	87.5	87.5	40.0	(30.5)
	9.4	39.1	28.1	10.9		4.7	10.9	35.9	21.9	10.9	3.1	
	0	0	4	4	8	0	0	2	2	1	3	8
	0	0	50.0	50.0	12.5	0	0	25.0	25.0	12.5	37.5	12.5
Yes	0	0	18.2	36.4	(50.8)	0	0	8.0	12.5	12.5	60.0	(46.8)
	0	0	6.3	6.3		0	0	3.1	3.1	1.6	4.7	
Total	6	25	22	11	64	3	7	25	16	8	5	64
	9.4	39.1	34.4	17.2	100.0	4.7	10.9	39.1	25.0	12.5	7.8	100.0

Mann-Whitney U	78	Mann-Whitney U	109
Wilcoxon Rank Sum W	406	Wilcoxon Rank Sum W	374
Z	-3.13	Z	-2.42
Significance	.002	Significance	.02

Table 272

Interview Data Analyses: Molarity - Problem 2
Problem Solved Correctly

Problems Correct	Structural Error - 1							
	0	1	2	4	5	7	8	Total
	11	1	8	6	24	5	1	56
	19.6	1.8	14.3	10.7	42.9	8.9	1.8	87.5
No	100.0	100.0	100.0	46.2	96.0	100.0	100.0	
	17.2	1.6	12.5	9.4	37.5	7.8	1.6	
	0	0	0	7	1	0	0	8
	0	0	0	87.5	12.5	0	0	12.5
Yes	0	0	0	53.8	4.0	0	0	
	0	0	0	10.9	1.6	0	0	
Total	11	1	8	13	25	5	1	64
	17.2	1.6	12.5	20.3	39.1	7.8	1.6	100.0

Chi Square	25.68
df	6
V	.63
Significance	.0003

Table 273

Interview Data Analyses: Molarity - Problem 2
Problem Solved Correctly

Problems Correct	Structural Error - 2							
	0	1	2	6	7	8	9	Total
	6	2	14	4	4	18	8	56
	10.7	3.6	25.0	7.1	7.1	32.1	14.3	87.5
No	100.0	100.0	100.0	100.0	100.0	69.2	100.0	
	9.4	3.1	21.9	6.3	6.3	28.1	12.5	
	0	0	0	0	0	8	0	8
	0	0	0	0	0	100.0	0	12.5
Yes	0	0	0	0	0	30.8	0	
	0	0	0	0	0	12.5	0	
Total	6	2	14	4	4	26	8	64
	9.4	3.1	21.9	6.3	6.3	40.6	12.5	100.0

Chi Square	13.36
df	6
V	.46
Significance	.04

Table 274

Interview Data Analyses: Molarity - Problem 3
Problem Solved Correctly

Problems Correct	Structural Error - 1									
	0	1	3	4	5	6	7	8	9	Total
	20	10	5	2	1	2	2	2	10	54
	37.0	18.5	9.3	3.7	1.9	3.7	3.7	3.7	18.5	84.4
No	100.0	100.0	83.3	100.0	50.0	100.0	100.0	100.0	55.6	
	31.3	15.6	7.8	3.1	1.6	3.1	3.1	3.1	15.6	
	0	0	1	0	1	0	0	0	8	10
	0	0	10.0	0	10.0	0	0	0	80.0	15.6
Yes	0	0	16.7	0	50.0	0	0	0	44.4	
	0	0	1.6	0	1.6	0	0	0	12.5	
Total	20	10	6	2	2	2	2	2	18	64
	31.3	15.6	9.4	3.1	3.1	3.1	3.1	3.1	28.1	100.0

Chi Square	20.17
df	8
V	.56
Significance	.01

Table 275

Interview Data Analyses: Molarity - Problem 3
Problem Solved Correctly

Problems Correct	Structural Error - 2						Structural Error - 3				
	0	1	2	3	4	Total	0	1	2	3	Total
	18	13	5	13	5	54	35	3	8	8	54
	33.3	24.1	9.3	24.1	9.3	84.4	64.8	5.6	14.8	14.8	84.4
No	100.0	100.0	33.3	100.0	100.0		100.0	100.0	100.0	44.4	
	28.1	20.3	7.8	20.3	7.8		54.7	4.7	12.5	12.5	
	0	0	10	0	0	10	0	0	0	10	10
	0	0	100.0	0	0	15.6	0	0	0	100.0	15.6
Yes	0	0	66.7	0	0		0	0	0	55.6	
	0	0	15.6	0	0		0	0	0	15.6	
Total	18	13	15	13	5	64	35	3	8	18	64
	28.1	20.3	23.4	20.3	7.8	100.0	54.7	4.7	12.5	28.1	100.0

Chi Square	38.72	Chi Square	30.29
df	4	df	3
V	.78	V	.69
Significance	<.0001	Significance	≤ .0001

Table 276

Interview Data Analyses: Molarity - Problem 3
Problem Solved Correctly

Problems Correct	Systemmatic Approach			No Answer Given			Algorithmic Reasoning Strategy		
	0	1	Total	0	1	Total	0	1	Total
No	30	24	54	32	22	54	48	6	54
	55.6	44.4	84.4	59.3	40.7	84.4	88.9	11.1	84.4
	100.0	70.6		76.2	100.0		100.0	37.5	
	46.9	37.5		50.0	34.4		75.0	9.4	
Yes	0	10	10	10	0	10	0	10	10
	0	100.0	15.6	100.0	0	15.6	0	100.0	15.6
	0	29.4		23.8	0		0	62.5	
	0	15.6		15.6	0		0	15.6	
Total	30	34	64	42	22	64	48	16	64
	46.9	53.1	100.0	65.6	34.4	100.0	75.0	25.0	100.0
	Chi Square		8.35	Chi Square		4.53	Chi Square		30.97
	df		1	df		1	df		1
	Phi		.40	Phi		.31	Phi		.74
	Significance		.004	Significance		.03	Significance		<.0001

Table 277

Interview Data Analyses: Molarity - Problem 3
Problem Solved Correctly

Problems Correct	Questions Correct 2	3	4	5	Total
	6	24	17	7	54
	11.1	44.4	31.5	13.0	84.4
No	100.0	96.0	77.3	63.6	(29.9)
	9.4	37.5	26.6	10.9	
	0	1	5	4	10
	0	10.0	50.0	40.0	15.6
Yes	0	4.0	22.7	36.4	(46.8)
	0	1.6	7.8	6.3	
Total	6	25	22	11	64
	9.4	39.1	34.4	17.2	100.0

Mann-Whitney U	127
Wilcoxon Rank Sum W	467
Z	-2.79
Significance	.005

Table 278

Interview Data Analyses: Molarity - Problem 3
Problem Solved Correctly

Problems Correct	Evaluation Sum			Comments About Solution		
	0	1	Total	0	1	Total
	50	4	54	21	33	54
	92.6	7.4	84.4	38.9	61.1	84.4
No	87.7	57.1	(31.4)	67.7	100.0	(35.6)
	78.1	6.3		32.8	51.6	
	7	3	10	10	0	10
	70.0	30.0	15.6	100.0	0	15.6
Yes	12.3	42.9	(38.6)	32.3	0	(16.0)
	10.9	4.7		15.6	0	
Total	57	7	64	31	33	64
	89.1	10.9	100.0	48.4	51.6	100.0
	Mann-Whitney U		209	Mann-Whitney U		435
	Wilcoxon Rank Sum W		386	Wilcoxon Rank Sum W		160
	Z		-2.09	Z		3.52
	Significance		.04	Significance		.0004

Table 279

Interview Data Analyses: Molarity - Total Problem Solved Correctly

Problems Correct	Systemmatic Approach					Nonsystemmatic Approach				
	0	1	2	3	Total	0	1	2	3	Total
0	8	9	9	13	39	22	10	5	2	39
	20.5	23.1	23.1	33.3	60.9	56.4	25.6	12.8	5.1	60.9
	100.0	100.0	47.4	46.4	(27.0)	48.9	83.3	100.0	100.0	(37.1)
	12.5	14.1	14.1	20.3		34.4	15.6	7.8	3.1	
1	0	0	10	5	15	13	2	0	0	15
	0	0	66.7	33.3	23.4	86.7	13.3	0	0	23.4
	0	0	52.6	17.9	(34.8)	28.9	16.7	0	0	(26.8)
	0	0	15.6	7.8		20.3	3.1	0	0	
2	0	0	0	8	8	8	0	0	0	8
	0	0	0	100.0	12.5	100.0	0	0	0	12.5
	0	0	0	28.6	(50.5)	17.8	0	0	0	(23.0)
	0	0	0	12.5		12.5	0	0	0	
3	0	0	0	2	2	2	0	0	0	2
	0	0	0	100.0	3.1	100.0	0	0	0	3.1
	0	0	0	7.1	(50.5)	4.4	0	0	0	(23.0)
	0	0	0	3.1		3.1	0	0	0	
Total	8	9	19	28	64	45	12	5	2	64
	12.5	14.1	29.7	43.8	100.0	70.3	18.8	7.8	3.1	100.0

Systemmatic Approach		Nonsystemmatic Approach	
KW Chi Square	14.68	KW Chi Square	9.95
df	9	df	9
Significance	.002	Significance	.02

Table 280

Interview Data Analyses: Molarity - Total Problem Solved Correctly

Problems Correct	No Answer Given				Algorithmic Strategy Only				
	0	1	2	Total	0	1	2	3	Total
0	19	15	5	39	5	11	18	5	39
	48.7	38.5	12.8	60.9	12.8	28.2	46.2	12.8	60.9
	52.8	65.2	100.0	(35.4)	27.8	55.0	90.0	83.3	(39.5)
	29.7	23.4	7.8		7.8	17.2	28.1	7.8	
1	7	8	0	15	5	7	2	1	15
	46.7	53.3	0	23.4	33.3	46.7	13.3	6.7	23.4
	19.4	34.8	0	(34.2)	27.8	35.0	10.0	16.7	(27.0)
	10.9	12.5	0		7.8	10.9	3.1	1.6	
2	8	0	0	8	6	2	0	0	8
	100.0	0	0	12.5	75.0	25.0	0	0	12.5
	22.2	0	0	(18.5)	33.3	10.0	0	0	(14.3)
	12.5	0	0		9.4	3.1	0	0	
3	2	0	0	2	2	0	0	0	2
	100.0	0	0	3.1	100.0	0	0	0	3.1
	5.6	0	0	(18.5)	11.1	0	0	0	(9.5)
	3.1	0	0		3.1	0	0	0	
Total	36	23	5	64	18	20	20	6	64
	56.3	35.9	7.8	100.0	28.1	31.3	31.3	9.4	100.0

No Answer Given		Algorithmic Strategy Only	
KW Chi Square	8.70	KW Chi Square	19.19
df	6	df	6
Significance	.03	Significance	.0003

Table 281

Interview Data Analyses: Molarity - Total Problem Solved Correctly

Problems Correct	Algorithmic Reasoning Strategy 0	1	2	3	Total	Comments About Solution 0	1	2	3	Total
0	34	5	0	0	39	9	13	12	5	39
	87.2	12.8	0	0	60.9	23.1	33.3	30.8	12.8	60.9
	91.9	45.5	0	0	(22.1)	50.0	48.1	85.7	100.0	(37.0)
	53.1	7.8	0	0		14.1	20.3	18.8	7.8	
1	3	6	5	1	15	1	12	2	0	15
	20.0	40.0	33.3	6.7	23.4	6.7	80.0	13.3	0	23.4
	8.1	54.5	71.4	11.1	(42.3)	5.6	44.4	14.3	0	(33.2)
	4.7	9.4	7.8	1.6		1.6	18.8	3.1	0	
2	0	0	2	6	8	6	2	0	0	8
	0	0	25.0	75.0	12.5	75.0	25.0	0	0	12.5
	0	0	28.6	66.7	(58.0)	33.3	7.4	0	0	15.1
	0	0	3.1	9.4		9.4	3.1	0	0	
3	0	0	0	2	2	2	0	0	0	2
	0	0	0	100.0	3.1	100.0	0	0	0	3.1
	0	0	0	22.2	(60.0)	11.1	0	0	0	9.5
	0	0	0	3.1		3.1	0	0	0	
Total	37	11	7	9	64	18	27	14	5	64
	57.8	17.2	10.9	14.1	100.0	28.1	42.2	21.9	7.8	100.0

	Algorithmic Reasoning Strategy	Comments About Solution
KW Chi Square	44.84	13.77
df	9	9
Significance	< .0001	.003

Table 282

Interview Data Analyses: Molarity - Total
Problem Solved Correctly

Problems Correct	Questions Correct					Questions Correct Without Prompting						
	0	1	2	3	Total	0	1	2	3	4	5	Total
0	5	23	7	4	39	3	7	15	11	2	1	39
	12.8	59.0	17.9	10.3	60.9	7.7	17.9	38.5	28.2	5.1	2.6	60.9
	83.3	92.0	31.8	36.4	(25.3)	100.0	100.0	60.0	68.8	25.0	20.0	(27.0)
	7.8	35.9	10.9	6.3		4.7	10.9	23.4	17.2	3.1	1.6	
1	1	2	10	2	15	0	0	7	2	5	1	15
	6.7	13.3	66.7	13.3	23.4	0	0	46.7	13.3	33.3	6.7	23.4
	16.7	8.0	45.5	18.2	(39.0)	0	0	28.0	12.5	62.5	20.0	(39.2)
	1.6	3.1	15.6	3.1		0	0	10.9	3.1	7.8	1.6	
2	0	0	4	4	8	0	0	2	3	1	2	8
	0	0	50.0	50.0	12.5	0	0	25.0	37.5	12.5	25.0	12.5
	0	0	18.2	36.4	(50.8)	0	0	8.0	18.8	12.5	40.0	(44.5)
	0	0	6.3	6.3		0	0	3.1	4.7	1.6	3.1	
3	0	0	1	1	2	0	0	1	0	0	1	2
	0	0	50.0	50.0	3.1	0	0	50.0	0	0	50.0	3.1
	0	0	4.5	9.1	(50.8)	0	0	4.0	0	0	20.0	(42.5)
	0	0	1.6	1.6		0	0	1.6	0	0	1.6	
Total	6	25	22	11	64	3	7	25	16	8	5	64
	9.4	39.1	34.4	17.2	100.0	4.7	10.9	39.1	25.0	12.5	7.8	100.0

KW Chi Square	19.23
df	9
Significance	.0002

KW Chi Square	10.07
df	15
Significance	.02

Nonsystematic approach. Moles, problem 1, total (Tables 220, 235), and molarity, total (Table 279). This approach was used by students getting the problem incorrect.

No answer given. Moles, problem 1 (Table 221), stoichiometry, total (Table 262), and molarity, problem 3, total (Tables 276, 280). Students not giving an answer got the problem incorrect.

Algorithmic strategy. Moles, problem 2, total (Tables 225, 235), stoichiometry, total (Table 263), and molarity, problems 1, 2, total (Tables 265, 271, 280). For moles, this strategy was used most for students getting two or three problems correct, for stoichiometry and molarity for students with one problem correct.

Algorithmic/reasoning strategy. Moles, all problems (Tables 221, 225, 231, 236), gas laws, problem 1, 3, total (Tables 240, 246, 250), stoichiometry, all problems (Tables 252, 255, 259, 264), and molarity, all problems (Tables 266, 270, 276, 281). This strategy predominated for successful problem solvers.

Random trial and error. Moles, problem 1 (Table 221), and stoichiometry, problem 2 (Table 256). This strategy was used more frequently by students who got the problem incorrect.

Misinterprets the problem. Gas laws, problem 3 (Table 246). An insufficient number of subjects were analyzed to make a judgement about the results.

Disregards information generated. Moles, problem 2 (Table 226). Students who missed the problem did this more frequently.

Misapplies information. Molarity, problem 1 (Table 266). Students who missed the problem did this more frequently.

Does not generate information. Moles, problem 2, total (Tables 226, 236). Students who missed the problem did this more frequently.

Evaluation. Gas laws, problem 3 (Table 246) and molarity, problem 3 (Table 278). Used more frequently by students who got the problem correct.

Comments about solution. Moles, all problems (Tables 222, 227, 231, 236), gas laws, problems 1, 2 (Tables 240, 244), stoichiometry, all problems (Tables 252, 256, 259, 263), and molarity, problems 1, 3, total (Tables 266, 278, 281). Students solving the problems incorrectly more frequently made comments about the solution.

Executive errors. Moles, problems 1, 2 (Tables 222, 227), and gas laws, problems 1, 2, total (Tables 240, 244, 251). Students who missed the problems made more executive errors.

Questions correct. Moles, all problems (Tables 223, 228, 232, 238), gas laws, problem 3 (Table 248), and molarity, all problems (Tables 267, 271, 277, 282). If students answered the questions correct, they more frequently got the problem correct.

Questions correct without prompting. Moles,all problems (Tables 224, 229, 233, 239), gas laws, problem 1, total (Tables 241, 251), stoichiometry, all problems (Tables 253, 257, 260, 264), and molarity, problems 1, 2, total (Tables 267, 271, 282). If the student got the questions correct without prompting, they were more likely to get the problem correct.

Structural errors.

1. Gas Laws 1 - 1, Table 242. Students who got the problem correct made no errors. Students who got the problem incorrect more frequently forgot to change to Kelvin temperature rather than making an error in the conversion.

2. Gas Laws 1 - 2, Table 242. Among students who got the problem incorrect the major error was to use the factor or proportion incorrectly. This error was more prevalent than forgetting to change to Kelvin temperature.

3. Gas Laws 2 - 2, Table 245. Students who did not work the problem correctly failed to set up the factor or proportion correctly. More made this error than those associated with Kelvin temperature conversion.

4. Gas Laws 3 - 2, Table 249. Students who did not get the problem correct frequently failed to convert the moles to volume and also did not set up a factor or proportion.

5. Stoichiometry 1 - 1, Table 254. The major error committed by students getting the problem wrong was failure to recognize the need to balance the equation before working the problem. This was followed by balancing the equation incorrectly.

6. Stoichiometry 2 - 1, Table 254. Students who solved the problem incorrectly failed to use the equation.

7. Stoichiometry 2 - 2, Table 256. Students who solved the problem incorrectly failed to use the equation.

8. Stoichiometry 3 - 3, Table 261. The error consisted primarily of not using the equation correctly for determining the product.

Molarity 1 - 1, Table 268. In the first step of the molarity problem, an equal number of students failed to calculate the molecular weight as calculated it correctly. Of students who missed the problem, more students calculated the molecular weight correctly than did not.

Molarity 2 - 1, Table 272. Students who missed the problem more frequently used the volume change incorrectly than failed to realize that a change occurred.

Molarity 2 - 2, Table 273. One major error existed, 25% of the students did not use the definition of molarity correctly. Thirty-two percent used the definition correctly and made the mL-L conversion correctly. These students did not use the volume change properly.

Molarity 3 - 1, Table 274. Of those missing the problem, more failed to calculate the molecular weight than either calculated it correctly or incorrectly.

Molarity 3 - 2, Table 275. In solving the molarity-stoichiometry problems, students frequently realized that a balanced equation must be used but either were unable to use it or used it incorrectly.

Molarity 3 - 3, Table 275. Of students who missed the problem equal numbers used the definition of molarity correctly as incorrectly.

A special note should be made concerning the chi-square analyses and their interpretation for the first five hypotheses. A very loose interpretation has been given to these data because of the coding system used. A more appropriate analysis (that time did not permit) would be to reclassify errors into single categories and analyze data in this manner. This has been done to some extent in the Detailed Analysis of Structural Errors that follows although no additional chi-square analyses were performed. The appropriate categories for the analyses are given in Tables 290, 293 and 296.

Hypothesis 6

There are no differences in the number of questions a student answers successfully according to verbal-visual preference, proportional reasoning ability, success in problem solving, the method taught in learning problem solving, and the number of problems solved correctly.

Data collected to test this hypothesis have been included in the summary charts (Tables 116, 122, 157, 194, 219). The number of questions answered correctly and the number of questions answered correctly without prompting were analyzed in terms of the other categories listed in the hypothesis. Results are summarized in Tables 283 and 284.

More detailed information about the significant findings are found in Tables 129, 130, 144, 154, 155, 169, 170, 186, 187, 238, 239, 251, 264 and 282. Results show that neither the teaching strategy nor students' verbal-visual preference made any difference as to the number of questions answered correctly with or without prompting. Answering the questions correctly was related to proportional reasoning ability except for the gas law questions. This is an interesting finding because the gas law questions were more qualitative in nature whereas the questions from the other units more quantitative.

Table 283

Summary of Findings of

"Answers Questions Correctly"

Analysis	Moles P	Gas Laws P	Stoichiometry P	Molarity P
Verbal-Visual Preference	-	-	-	-
Proportional Reasoning Ability	.005	-	.03	.001
Success on Tests	<.0001	-	.01	-
Teaching Strategies	-	-	-	-
Problem Solved Correctly	.004	-	-	.0002

Table 284

Summary of Findings for

"Answers Questions Correctly Without Prompting"

Analysis	Moles P	Gas Laws P	Stoichiometry P	Molarity P
Verbal-Visual Preference	-	-	-	-
Proportional Reasoning Ability	<.0001	-	.04	.002
Success on Tests	<.0001	-	.05	-
Teaching Strategies	-	-	-	-
Problem Solved Correctly	<.0001	.02	.002	.02

Success on the tests and solving the problem correctly was also dependent on the number of questions a student answered successfully. The exception to this was the gas law problems where the questions were more conceptual rather than quantitative.

Detailed Analysis of Structural Errors

Because of the importance of the structural error section, more detailed analyses were performed. For the moles interviews, a listing of the types of errors the students made in solving the problems was formulated. This was done before tapes from the other units were analyzed. Because this yielded interesting information, special structural error coding sheets unique to each of the other units were drawn up and used in their subsequent analyses.

Moles Structural Errors. A summary of the results of students' responses to questions asked students at the beginning of the interviews and a summary of the errors made are given in Tables 285 - 287. As stated previously, the purpose of including questions was to test students' knowledge of facts and concepts thought to be essential to solve the problem. Although the percentages of students answering correctly improved with prompting, it was rather discouraging to find the initial percentages so low. (See Table 285).

One might argue that the reason that the initial response was poor was that the instruction was insufficient. This was probably not the case. Teachers commented that by using the packets they felt that there was much more thorough instruction than has been previously given. Students generally obtained very high scores on the immediate posttests indicating that they had at least memorized the facts and concepts at one point in time. For some reason these concepts have not been thoroughly understood and/or are not retained by the students. Even though correct answers were supplied to students who missed the questions, this was probably not very useful in helping them solve the problems because they did not understand the concepts involved. The difference in findings in

Table 285

Moles Questions:

Summary of Results

Question		Correct N	Correct %	Correct Without Prompting N	Correct Without Prompting %
1	The formula for calcium hydroxide is $Ca(OH)_2$. How many atoms of each element are present in a molecule of calcium hydroxide?	67	91	38	51
2	If you had a mole of something, what would that mean to you?	48	65	5	12
3	How many particles are in one mole?	68	92	64	86
4	What volume would one mole of a ideal gas occupy at STP?	64	86	58	78
5	How would you determine the mass of one mole of iron?	51	69	34	46
6	How would you determine the mass of one mole of ammonia (NH_3)?	68	92	54	73

Table 286

Moles: Analyses of Problems

Problem Number	N	Rt.No.	Skill				Errors				
							X				
1M	24 =	16	Moles → Mass				M	— Ma	5		
1Mo	25	12	Moles → Molecules				M	— Mo	9		
1V	25	11	Moles → Volume				M	— V	10		
	--	--									
	74	39	(53%)								
					÷		X				
2MMo	29	11	Mass → Molecules	Ma	M	9	M	Mo	4		
2MoV	22	14	Molecules → Volume	Mo	M	5	M	V	3		
2VM	23	10	Volume → Mass	V	M	4	M	Ma			
	--	--									
	74	35	(47%)								
					÷		X				
3MA	24	3	Mass → Atoms	Ma	M	7	M	Mo		Mo	A
3VA	23	3	Volume → Atoms	V	M	8	M	Mo		Mo	A
3VM	19	4	Volume → Mass Atoms	V	M		M	Ma	1	Ma (Mol)	Ma (At)
	--	--									
	66	10	(15%)								

Table 287

Moles:

Structural Errors

(PPRT = 13.42)

I.		Wrong operation used but correct concepts
	3	Multiply volume x 22.4 instead of dividing
	1	Multiplies atomic masses instead of adding
	1	Divides mol. wt. by moles instead of multiplying
	1	Divides 22.4 liters by liters instead of reverse
	1	Divides 6.02×10^{23} molecules by number of particles instead of reverse
II.		Conceptual, confused about meaning of mole
	1	Finds moles and calls it grams
	2	Finds moles and calls it liters
	2	Finds moles and calls it molecules
	1	Leaves answers in moles instead of converting to mass
	1	Leaves answers in moles of atoms rather than number of atoms
III.		Use wrong conversion factor + conceptual
	10	Use mol. wt. instead of 22.4 1
	4	Find the mass instead of volume
	2	Finds volume instead of mass but calls it grams
	2	Multiply mass x 22.4 1
	2	Divides mol. wt. into liters
	1	Divides mol. wt. by 22.4
	4	Multiply mass by 6.02×10^{23}
	2	Multiply volume by 6.02×10^{23}
	4	Use mol. wt. instead of 6.02×10^{23}
IV.		Leaves out moles
	1	Finds atoms in formula instead of atoms in moles present
	1	Converts grams to molecules without mole conversion
V.		Miscellaneous
	1	Finds molecules instead of atoms
	1	Finds total mass rather than mass of part
	2	Confused by additional information in problem (STP)

Tables 283 and 284 are slight indicating that giving students the answer made little difference in their solving problems correctly.

Table 282 breaks the errors down in terms of the types of problems students solved in each set. Problems 1M, 1Mo, and 1V differed from one another in that they involved moles as mass, molecules, and volume. Students had been given (in the question section) the prerequisite facts to answer these problems correctly. Many errors were made even though they had the information within minues beforehand. The smallest numbers of errors were made in changing moles to mass rather than to molecules or to volume. Apparently, students perceive the mole as mass rather than a volume or a number. Equal emphasis had been given to all three parameters in the instruction.

The second set of problems involved two conversions. One of these used division to change from mass, molecules, or volume to moles; the other involved multiplication to change from moles to molecules, volume, or mass. Results indicate that more errors were made with the division concept than with multiplication. In this case the largest numbers of errors were made with the mass concept. The reason for this was probably due to the fact that the volumes given were multiples of 22.4 and the number of molecules given were multiples of 6.02×10^{23}. This may have cued students sufficiently to enable them to see that division was needed to solve the problems. More evidence for this stems from the fact that more students got the molecules-volume problem correct than the ones involving mass.

Problems in the third set each involved transfer. Students had to tell the number of atoms or the mass of atoms after they solved the problem in terms of molecules. Students had not encountered problems of this nature before but should have been able to work the problems correctly if they had understood all the problems up to this time. From Table 286 it can be seen that very few students got these problems correct. As in the case with the second set of problems, a larger proportion of students missed the mass to mole conversion than the volume to mole conversion. Once students got this far they usually did not know hot to proceed.

In Table 287 the errors that students made in solving the moles problems were summarized according to five categories. In some cases, students used a wrong operation. Large numbers of students showed complete lack of the meaning of the mole (categories II and III) as is shown when students did not know what they had solved for or used the wrong conversion factors.

Gas Laws Structural Errors. A summary of the prerequisite questions that students answered correctly and the summary of the structural code results are given in Tables 288 to 290. The questions that were asked in this unit were more conceptual (qualitative) than quantitative. (Two other questions that should have been asked but were not because of lack of foresight were as follows: (1) How many liters of a gas were equal to 250 mL? and (2) What is the meaning of STP?) As with the questions for moles, many students needed prompting to get them correct. Once a student answered the first question correct or was given the correct answer, this acted as a cue for questions two and three. Question four was included to determine if students really understood the gas law concept or had only memorized the result. From the law percentage getting the answer correct, it appears that few students really thought about the concept correctly. Most probably memorized the results.

Table 289 gives the percentage of students who got the problem correct for each of the three problem categories and the number of students who made structural errors as they appeared on the coding sheets. As can be expected as the problems become more complex, fewer students were able to solve them. Problem 3 was a combination gas law and mole problem that required students to synthesize what they had learned in the gas law unit with that learned in the moles unit.

Table 288

Gas Law Questions:

Summary of Results

Question		Correct N	Correct %	Correct Without Prompting N	Correct Without Prompting %
1	What would happen to the volume of a gas sample if the pressure on the sample was increased and the temperature held constant?	61	95	42	66
2	What would happen to the volume of a gas sample if the temperature was increased and the pressure held constant?	64	100	52	81
3	What would happen to the temperature of a gas sample if the pressure on the sample was decreased and the volume held constant?	59	92	49	77
4	What would happen to the pressure of a gas sample if the temperature and the volume were both increased?	19	30	11	17

Table 289

Gas Law Problems:

Structural Code Results

(PPRT = 12.14)

	Problem Distribution			Correct		Structural Error Coding					
Problem	TP	TV	PV	N	%	A	N	B	N		
1	25	18	21	29	45	0	1	0	5		
						1	19	1	1		
						2	8	2	17		
						3	1	3	41		
						4	35				
Problem	TVP	TPV	PVT	N	%	A	N	B	N		
2	18	20	26	17	27	0	4	0	5		
						1	-	1	3		
						2	2	2	2		
						3	4	3	20		
						4	2	4	6		
						5	6	5	28		
						6	43				
						7	2				
						8	1				
Problem	M-TV	M+TV	MPV	N	%	A	N	B	N	C	N
3	20	21	23	2	3	0	29	0	26		
						1	10	1	1	1	11
						2	4	2	9		
						3	1	3	1		
						4	20	4	13		
								5	-		
								6	-		
								7	6		
								8	3		
								9	5		

Table 290

Gas Law Problems:

Description and Summary of Structural Coding

Problem	Category		N	%
1	A	Doesn't get this far	1	2[a]
		Kelvin temperature not required	19	30[b]
		Fails to change to Kelvin temperature	8	18[c]
		Makes error in calculating Kelvin temperature	1	2
		Converts to Kelvin temperature correctly	35	80
	B	Doesn't get this far	5	8[a]
		Doesn't set up factor or proportion	1	2[b]
		Inverts a factor or sets up wrong proportion	17	29
		Sets up problem correctly	41	69
2	A	Doesn't get this far	4	6[a]
		Fails to change to Kelvin temperature (beginning)	4	7[b]
		Fails to change to Kelvin temperature (end)	8	13
		Makes error in calculating Kelvin temperature	8	13
		Converts all Kelvin temperatures correctly	43	70
	B	Doesn't get this far	5	8[a]
		Doesn't set up factor or porportion	3	5[b]
		Disregards one of the conditions	8	14
		Inverts a factor or sets up wrong proportion	26	43
		Correct set up (regardless of Kelvin temperature)	28	47
3	A	Doesn't get this far	29	45[a]
		Kelvin temperature not required	10	29[b]
		Fails to change to Kelvin temperature	4	16
		Makes error in calculating Kelvin temperature	1	4
		Converts to Kelvin temperature correctly	20	80
	B	Doesn't get this far	26	41[a]
		Fails to convert moles to volume	14	37[b]
		Doesn't set up a factor or proportion	27	71
		Inverts a factor or sets up wrong proportion	1	3
		Sets up problem correctly	6	16
		Converts to liters incorrectly	8	21
	C	Confused about STP	11	17

---

[a] Based on all cases.

[b] Remaining % 's based on those who got that far (except where indicated).

[c] Based on cases in which a change was required.

It was a transfer item and only 3% of the students solved it correctly.

Because of the coding system, several structural errors were grouped together on the original coding sheets. These were ungrouped and added together to produce the results found in Table 290.

For problems in category 1, the major error was that students did not set up a correct factor or proportion. Eighteen (18%) percent of the students who attempted it did not remember to change to Kelvin temperature.

Similar results are found for the second set of problems. Students generally converted temperatures to Kelvin correctly. The major error made was in setting up the proportions. For problems in group 3 which involved changing moles to volume as one of the first steps, many students said the problem just couldn't be done and proceeded no further. Thirty-seven (37%) percent of those who proceeded did not convert moles to volume and seventy-one (71%) percent did not set up a factor or a proportion.

Because of time restrictions, no further analysis of the tapes were made to determine just what students do in the calculation when they get the problem wrong. The coding sheet only determined what they failed to do when they were incorrect. A more detailed analysis of the tapes should reveal particular errors students made and where the confusion in concept development lies. In addition to the above, chi-square analysis using the same categories as given in Table 290 would be appropriate. These should replace those given previously for each of the first five hypotheses for structural errors.

Stoichiometry Structural Errors. Tables 291 - 293 summarize the data for structural errors for the stoichiometry problems. Table 291 gives the results of how students responded to the questions that tested background information needed to solve the problems. Six of the questions were identical to those asked in the "Moles Problem" interviews (Table 285) The percentages show only a slight increase indicating that even though these

Table 291

Stoichiometry Questions:

Summary of Results

Question		Correct		Correct Without Prompting	
		N	%	N	%
1	The formula for calcium hydroxide is $Ca(OH)_2$. How many atoms of each element are present in a molecule of calcium hydroxide?	61	92	32	48
2	If you had a mole of something, what would that mean to you?	45	68	12	18
3	How many particles are in one mole?	64	97	59	89
4	What volume would one mole of an ideal gas occupy at STP?	58	88	52	79
5	How would you determine the mass of one mole of iron?	46	70	31	47
6	How would you determine the mass of one mole of ammonia (NH_3)?	62	94	50	76
7	How would you go about balancing the following equation: $NaCl_{(aq)} + H_2SO_{4(aq)} \longrightarrow Na_2SO_{4(aq)} + HCl_{(aq)}$	64	97	54	82

Table 292

Stoichiometry Problems:

Structural Code Results

(PPRT = 12.82)

	Problem Distribution			Correct		Structural Error Coding					
Problem	M	V	P	N	%	A	N	B	N		
1	18	27	21	18	27	0	2	0	9		
						1	23	1	32		
						2	13	2	4		
						3	28	3	21		
Problem	MM	MV	MP	N	%	A	N	B	N		
2	26	23	17	17	26	0	2	0	13		
						1	34	1	23		
						2	30	2	12		
								3	18		
Problem	HH	SS1	SS2	N	%	A	N	B	N	C	N
3	22	24	20	5	8	0	6	0	30	0	38
						1	28	1	3	1	11
						2	32	2	5	2	10
								3	28	3	7

Table 293

Stoichiometry Problems:

Description and Summary of Structural Coding

Problem	Category		N	%
1	A	Doesn't get this far	2	3[a]
		Balances equation correctly	23	36[b]
		Balances equation incorrectly	13	20
		Does not attempt to balance equation	28	44
	B	Doesn't get this far	9	14[a]
		Uses equation correctly in solving problem	32	56[b]
		Uses equation incorrectly in solving problem	4	7
		Does not use equation in solving problem	21	37
2	A	Doesn't get this far	2	3[a]
		Checks to see that equation is balanced	34	53[b]
		Does not check to see that equation is balanced	30	47
	B	Doesn't get this far	13	20[a]
		Uses equation correctly in solving problem	23	43[b]
		Uses equation incorrectly in solving problem	12	23
		Does not use equation in solving problem	18	34
3	A	Doesn't get this far	6	9[a]
		Checks to see that equation is balanced	28	47[b]
		Does not check to see that equation is balanced	32	53
	B	Doesn't get this far	30	45[a]
		Uses equation correctly for determining excess	3	8[b]
		Uses equation incorrectly for determining excess	5	14
		Does not use equation for determining excess	28	78
	C	Doesn't get this far	38	58[a]
		Uses equation correctly for determining product	11	39[b]
		Uses equation incorrectly for determining product	10	36
		Does not use equation for determining product	7	25

---

[a] Based on all cases.

[b] Remaining %'s based on those who got that far (except where indicated).

concepts were reviewed and used in this unit, there was no substantial gain in knowledge. The new question which was concerned with balancing an equation was answered correctly by ninety-seven (97%) percent of the students when prompted.

Table 292 gives the percentage of students who got the problems correct according to categories. The first problems that involved two steps (changing from mass, volume, or particles of one substance to moles of another) was apparently as difficult for students to solve as problems in the second set that involved three steps (changing from mass, volume, or particles of one substance to mass, volume, or particles of another). The reason why this may have been as easy was because in the problems of set 1, students were given an unbalanced equation that they had to balance before proceeding whereas the problems in set 2 contained balanced equations. This is verified by examining Table 293 that shows the major reason for students missing the problems in set 1 was failure to use a balanced equation. In the problems of set 2, many students did not overtly check to determine if the equation was properly balanced. However, in this set of problems, a much larger percentage of students used the equation incorrectly.

Problems from set 3 were transfer problems that involved finding the limiting reagent. Only eight (8%) percent of the students who attempted the problem got it correct. Forty-five (45%) percent did not get beyond checking to see if the equation was balanced. The major difficulty in solving the problem was in determining the excess or the limiting reagent.

The same comments concerning further analysis that were made for the gas law problems can be made for the stoichiometry problems. Time did not permit an analysis of errors that students who missed the problem made nor the reanalysis of data using chi-square with the categories used in Table 293.

Molarity Structural Errors. Results of the questions asked in the "Molarity Problem" interviews and the structural errors are given in Tables 294-296. In the question section, one question concerning the L-mL conversion was asked that should have been asked in the "Gas Law Problem" interview. With prompting ninety-two (92%) percent were able to make the conversion. Questions 1 and 2 on the determination of the masses of moles had been asked during both the "Moles Problems" and "Stoichiometry Problems" interviews. The percentage of students who answered these questions correct was approximately ten (10%) percent higher than previously. Apparently this conversion was used so frequently that by the end of the school year when the interviews took place, eighty-eight (88%) and ninety-eight (98%) percent of the students interviewed could do this when prompted.

Question 4 on "define molarity in your own words" most frequently brought the memorized response "moles per liter". This answer was accepted as correct even though students did not specify "liter of solution".

To test whether students had simply memorized the definition of molarity or really understood it, question 5 on "how would you make up one liter of a two molar sodium chloride solution" was included. Only eight (8%) percent of the students interviewed were able to answer this without prompting. Even with prompting, only twenty-seven (27%) percent gave a correct answer. An answer was considered to be correct if students said that 2 moles or approximately 116 g of sodium chloride were dissolved in 1000 mL or 1 liter of water instead of solution. Most students had no understanding of the physical meaning of molarity.

Table 295 shows the percentage of students getting the problems in each category correct. Problems in the first set involved the direct application of the definition of molarity as molarity = moles/liters. Thirty (30%) percent of the students were able to solve this type of problem. From Table 296 it can be seen that thirty-three (33%) percent of the students who attempted the problem

Table 294

Molarity Questions:

Summary of Results

Question		Correct		Correct Without Prompting	
		N	%	N	%
1	How would you determine the mass of one mole or iron?	56	88	38	59
2	How would you determine the mass of one mole of ammonia (NH_3)?	63	98	54	84
3	How many milliliters are equal to 2.5 liters?	59	92	40	63
4	Define molarity in your own words.	35	55	25	39
5	How would you make up one liter of a two molar sodium chloride solution?	17	27	5	8

Table 295

Molarity Problems:

Structural Code Results

(PPRT = 13.36)

	Problem Distribution			Correct		Structural Error Coding					
Problem	ML	G	MO	N	%	A	N	B	N		
1	18	23	23	19	30	0	7	0	10		
						1	8	1	2		
						2	-	2	7		
						3	4	3	-		
						4	1	4	-		
						5	-	5	-		
						6	2	6	14		
						7	3	7	4		
						8	8	8	26		
						9	31	9	1		
Problem	MOD	MOC	MOV	N	%	A	N	B	N		
2	25	16	23	8	13	0	11	0	6		
						1	1	1	2		
						2	8	2	14		
						3	-	3	-		
						4	13	4	-		
						5	25	5	-		
						6	-	6	4		
						7	5	7	4		
								8	26		
								9	8		
Problem	WA	GA	GA	N	%	A	N	B	N	C	N
3	22	23	19	10	16	0	20	0	18	0	35
						1	10	1	13	1	1
						2	-	2	15	2	8
						3	6	3	13	3	18
						4	2	4	5		
						5	2				
						6	2				
						7	2				
						8	2				
						9	18				

Table 296

Molarity Problems:

Description and Summary of Structural Coding

Problem	Category		N	%
1	A	Doesn't get this far	7	11[a]
		Doesn't calculate molecular weight	8	14[b]
		Calculates molecular weight incorrectly	5	9
		Calculates molecular weight correctly	43	75
		Uses molecular weight incorrectly	11	19
		Uses molecular weight correctly	34	60
	B	Doesn't get this far	10	16[a]
		Doesn't use definition of molarity	2	4[b]
		Uses definition of molarity incorrectly	21	39
		Uses definition of molarity correctly	26	48
		Error in mL-L conversion	18	33
		Changes mL-L correctly	27	50
2	A	Doesn't get this far	11	17[a]
		Realizes that volume changes	1	2[b]
		Fails to use volume change	8	15
		Uses volume change correctly	13	24
		Uses volume change incorrectly	25	45
		Doesn't get final volume	5	9
	B	Doesn't get this far	6	9[a]
		Doesn't use definition of molarity	2	3[b]
		Uses definition of molarity incorrectly	14	24
		uses definition of molarity correctly	38	66
		Error in mL-L conversion	8	14
		Both definition and mL-L change correct	26	45
3	A	Doesn't get this far	20	31[a]
		Doesn't calculate molecular weight	10	23[b]
		Calculates molecular weight incorrectly	4	9
		Calculates molecular weight correctly	26	59
		Uses molecular weight incorrectly	6	14
		Uses molecular weight correctly	22	50
	B	Doesn't get this far	18	28[a]
		Realizes equation must be used	13	28[b]
		Uses balanced equation correctly	28	61
		Uses balanced equation incorrectly	13	28
		Doesn't realize equation must be used	5	11
	C	Doesn't get this far	35	55[a]
		Doesn't use definition of molarity	3	10[b]
		Uses definition of molarity incorrectly	8	28
		Uses definition of molarity correctly	18	62

[a] Based on all cases.

[b] Remaining %'s based on those who got that far (except where indicated)

made a mL-L conversion error, and thirty-nine (39%) percent used the definition of molarity incorrectly. Nineteen (19%) percent of the students who attempted to work the problem did not use the molecular weight to find moles properly.

The second set of problems involved changing the volume of solution by either diluting it or concentrating it by boiling. Only thirteen (13%) percent of the students could handle this kind of problem even though most students could do problems of this nature immediately after instruction. The major error made was that students did not use the volume change correctly. (Instead of finding moles first and dividing by the total volume students frequently added or subtracted the volumes before working with the given molarity.) Knowing that such a large percentage of students did not have the conceptual knowledge of what molarity is (from responses to question 5) this comes as no surprise.

Problems in set 3 were transfer problems that involved the concept of molarity applied in a stoichiometry problem. A slightly greater percentage of students got this problem correct than got the problem from set 2 correct. It was probably the same students who understood the concepts. Fifty-five (55%) percent of the students did not understand the problem sufficiently to even use the definition of molarity. Sixty-one (61%) percent of those who got that far (forty-four (44%) percent of original students) used the balanced equation correctly. Once students got the number of moles of H_3PO_4 , many could not proceed to use the moles with the liters to find the molarity.

Comments made previously about further analysis of the tapes of the "Gas Law Problem" and "Stoichiometry Problems" interviews apply here. Further analyses are needed to determine specific conceptual errors that students made while attempting to solve the problems.

Summary and Conclusions

Results of this interview study must be seen in relation to the aptitude by treatment interaction study as well as the findings of a similar study by Nurrenbern.

The interview study was concerned with six hypotheses. In addition, structural errors students made while solving problems from four chemistry units were identified.

Of the six hypotheses tested, two were related to aptitudes measured in the aptitude by treatment interaction study. These were the verbal-visual preference and the proportional reasoning ability of students. Because of lack of time and because it was not anticipated that mathematics anxiety would have significant interaction, data were not analyzed according to students' mathematics anxiety. An analysis of this data would be appropriate and might yield useful results.

Of the two aptitudes for which interview data were analyzed, the one of most interest was students' proportional reasoning ability. Results for verbal-visual preference were very sparse as they were in the case for the aptitude by treatment interaction study. Findings from the interviews corroborate those found in the other study.

The reason why the proportional reasoning ability is of interest is because the study done by Nurrenbern compared students' problem solving skills according to whether they were classified as concrete or formal operational. Because proportional reasoning ability is one of the schema that comprises the formal operational stage, there would probably be a high correlation between students classified as formal and their proportional reasoning ability.

In all the comparisons between the results obtained, it must be remembered that Nurrenbern's study was concerned only with stoichiometry limiting reagent problems which less than 1% of the students interviewed were able to work correctly.

Nurrenbern's classification system was modified in part in this study but enough similarity remains to make some comparisons. One general category that was used in both studies was reading/organizing skills. In Nurrenbern's study formal students were found to read and organize more frequently. This was particularly true for rereading and using mnemonic notation. In this study similar results were found for rereading and use of mnemonic notation. Although there were no significant differences for every problem, where differences occurred, they always favored the high proportional reasoning students. Comparisons with the general category "Reading/organizing" are inappropriate as all subcategories were not identical.

Nurrenbern also found that formal operational students used evaluation techniques more frequently than concrete operational students. She also made the comment that neither group used evaluation techniques to any great extent. In this study, no differences between high and low proportional reasoning ability students were found for evaluation techniques. Very few students evaluated their solutions to the problems.

As in the Nurrenbern study, it was found that few students used recall techniques. The number of statements coded for recall was so low in this study that the data were not analyzed.

In the area of the type of approach and reasoning that students used to solve the problems, results of the two studies are in accord. In the Nurrenbern study, no significant differences were found for formal and concrete thinkers, however, when algorithmic/reasoning strategies were used, they were used by formal operational students. In this study, students with high proportional reasoning ability were found to use a systemmatic approach and algorithmic/reasoning strategies more frequently than low proportional reasoning students on a large number of the problems. Nurrenbern comments that the results in her study might not have been significant because of the difficulty of the problems. She found as did we, that many formal students actually go about solving the problems relying strictly on algorithms.

A comparison of the structural errors made in the two studies is impossible to make. The reason for this is that the problems in this study were for the most part easier than those in the Nurrenbern study. The only comparable problem was the third stoichiometry problem which was a limiting-reagent problem. Even for this problem, however, a balanced equation was given. The major structural error found for this problem was that students fail to use the equation for determining the excess to solve it. More detailed analysis of the structural errors were presented in the Results section.

In this study, unlike the Nurrenbern study, instruction on problem solving was controlled through the use of the packets devised for the aptitude by treatment interaction study. This has its advantages and disadvantages. The major advantage was that a minimum amount of instruction was insured by knowing that students completed the booklets. However, there is the disadvantage in that it might be argued that the instruction was insufficient and not typical of what a student would normally receive. Teachers in the study felt it was sufficient, and if not,could supplement it with additional work. Because students learned by using the four different strategies, it was of interest to determine if this had any effect on students'problem solving techniques.

Results indicated few differences in students' problem techniques according to method taught. Students who learned to solve problems by the factor-label method and proportionality tended to be more systemmatic in their approach and more overtly used the approach taught. This was to be expected as these methods lend themselves to overt expression. An interesting finding, although found only on one gas law problem, was that students taught by analogies used algorithmic/

reasoning strategies more frequently than by the proportionality method. This finding is offset by the finding that the analogy method also produced the greatest use of random trial and error for a stoichiometry problem.

In no instance did one method produce more structural errors than another. Thus indicating that as far as presenting the material, all methods were equivalent. Major conclusions in this study concerning the appropriate methods for teaching the various chemistry topics should be made from the aptitude by treatment interaction study where data were analyzed in much greater detail according to students' aptitudes.

The major reason for conducting the interview study was to compare students who were successful problem solvers with those who were not. Results have been presented for students defined successful according to test scores (Hypothesis 3) and according to success on the problem solved during the interview (Hypothesis 5). Specific results are given in the Results section. Discussion here is limited to commonality of the findings. For students classified as successful and for students who got the problem correct, the use of reading and organizing skills was more frequent. This was true for different problems, however, and was not consistent across all problems. The use of mneumonic notation was much more prevalent and consistent across problems for successful students and those who got the problem correct. Two other common characteristic across most problems for both of these groups were their more frequent use of systemmatic approaches and their use of algorithmic/reasoning strategies. This is not to say that more students in these classification used reasoning strategies more frequently than algorithmics. This was not the case. They used reasoning strategies more than nonsuccessful students or students who got the problem incorrect.

Analysis of the structural errors for both of these groups had some similarities. Students of low success or who missed gas law problem 3 failed to set up a factor correctly. They also failed to use the equation in solving stoichiometry problems 1 and 2. For molarity problem 3, low success students failed to perceive the need for using the equation whereas those getting the problem incorrect were unable to use the equation correctly. On this same problem, low success students didn't use the definition of molarity correctly.

From both the structural errors students made and from the findings related to Hypothesis 6, it is apparent that one of the major reasons students do not solve problems correctly is that they do not understand the prerequisite facts and concepts. In the Results section considerable discussion is given to the structural errors made for each unit of chemistry. For this reason, the remarks here will be brief. Because of lack of time, the analysis of the tapes was not as comprehensive as it might have been. For the moles unit, no special coding sheet was devised for structural errors, but the specific errors that students made were recorded and synthesized into a coherent list. For the other three units, the special sheet was devised that listed what students failed to do but did not provide for obtaining the specific errors that students made. A reanalysis of the tapes would provide this useful information.

Four general conclusions and recommendations can be drawn from this interview study.

1. If students do not understand the chemistry concepts (as is evident from low success on prerequisite questions and structural error analysis) even if answers to prerequisite questions are given, students will not be successful in solving chemistry problems.

2. Different types of errors are made by different students. It is very hard to classify them. These different types of errors require different types of remediation. Sometimes it is a matter of understanding the concept, other times its the arthmetic (particularly the division concept) and frequently students fail to memorize the necessary facts (such as 1 mole = 22.4 L at STP or contains 6.02×10^{23} particles).

3. Students who are successful generally use more organizing skills and use mneumonic notation. Students should be encouraged to use these skills in solving problems.

4. It would be very useful for individual teachers to determine specific errors that individual students make so that remediation might take place. This might be accomplished by recording on audio tape students actually solving problems. If this is not possible, teachers should determine through a short test, if students have the necessary prerequisite skills for solving problems and if they do not, provide the necessary instruction.

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APPENDIX A

Permission Forms

School Corporation. 431
Individual Student. 432
University Human Subjects 433

INDIANA UNIVERSITY
School of Education

INDIANA UNIVERSITY
at Bloomington

INDIANA UNIVERSITY-
PURDUE UNIVERSITY *at Indianapolis*

The problem solving research we are conducting in high schools in Indiana has recently been funded by the National Science Foundation. One of their requirements is that we obtain written approval for participation in the project from a school authority who has followed any necessary procedures in the school system.

We are, therefore, asking you to give us the needed written approval.

I have been supplied with the purposes, content, and benefits of the NSF supported project "Facilitating Problem Solving in High School Chemistry" and have given my approval for participation.

Signature

Title

School

EDUCATION BUILDING, 3RD AND JORDAN, BLOOMINGTON, INDIANA 47401
TEL. NO. 812 - 337-5213

INDIANA UNIVERSITY
School of Education
EDUCATION BUILDING Rm. 204
BLOOMINGTON, INDIANA 47401

TEL. NO. 812 337-8659

May 31, 1979

Dear Student and Parent:

From our past experience in teaching high school chemistry (16 years combined experience) we have found that an integral part of chemistry in which most students have difficulty is problem solving. Last year we examined the questions (and how students answered them) on a national chemistry exam commonly given in schools in this area. We found that the questions students found most difficult were those involving problem solving (56% of the questions).

This was one of the reasons that motivated us to try to find methods of helping students solve chemistry problems more successfully. What we would like to do is try out these methods as supplementary to regular instruction on problem solving. All students will receive their normal instruction. The supplementary methods that are alternative strategies that have been used by other teachers should strengthen the students' problem solving skills. The supplementary methods will be contained in study guides that students will use in learning eight chemistry concepts involving problems. Each study guide is one class period in length.

In order to measure the success of the supplementary instruction for particular types of students, students receiving the instruction will be expected to complete short tests on their ability to use proportions (30 min.), their preference for learning through visual or verbal methods (20 min.) and their attitude toward using math (20 min.). Tests will be administered in September. All results will be kept confidential, and will have no bearing on the student's grade. If a student would be interested in his/her own test results, these will be available on an individual basis. Of course, a student may withdraw from the program at any time. Please feel free to contact us at 812-337-8658 about the procedures.

Sincerely,

Dorothy Gabel
Robert Sherwood
Science Education, Indiana University

____I would like to participate in this program

____I am not willing to participate in this program

Student's signature_______________

Parent's signature _______________
(if under 18)

Indiana University / Bloomington Campus
Committee for the Protection of Human Subjects

SUMMARY SAFEGUARD STATEMENT
to be completed by
All Investigators Utilizing Human Subjects in Research

PROJECT TITLE: Facilitating Problem Solving in High School Chemistry

GRANT NUMBER (IF KNOWN):

PRINCIPAL INVESTIGATOR(S): Dorothy L. Gabel (typed name) (signature)

Robert D. Sherwood (typed name) (signature)

STATUS: ☒ FACULTY ☒ STUDENT ☐ OTHER (specify)

If student, name of faculty sponsor: Dr. Dorothy L. Gabel (typed name) (signature)

DEPARTMENT: Science Education DATE: 5/31/79

CAMPUS ADDRESS: Education Bldg., Rm. 204 CAMPUS PHONE: 337-6858

PROPOSED FUNDING:

☒ EXTERNAL AGENCY/NAME NSF ☒ IU/TYPE Spencer ☐ UNFUNDED/TYPE

INSTRUCTIONS: In the spaces below (use additional sheets where necessary):

Check appropriate boxes for subject population involved if it includes: ☒ minors, ☐ fetuses or abortuses, ☐ pregnant females, ☐ mentally retarded, ☐ mentally disabled, ☐ prisoners. If any of the above are used, state the necessity for doing so under item 1.

1. Briefly describe the purpose and nature of the proposed research. State what, if any, benefit is to be gained by the subject(s), what information is to be added to the general body of knowledge as a result of this research, and where the research will be conducted. (This includes research training grants. Each project should be treated separately.)

Student guides using four methods of problem solving (two visual and two verbal) will be prepared and used in instruction for eight chemistry topics by 600 high school students who are randomly assigned to treatments. Problem solving skills resulting from the four methods and measured by short and long term tests will be compared for students of varying proportional reasoning ability and different visual-verbal preferences. Data for this aptitude by treatment interaction study will be analyzed using multiple regression techniques.

It is anticipated that from this study preferred methods of teaching problem solving to different types of high school students will be made known. The research will be conducted within a 60 mile radius of Indianapolis in public high schools.

2. List *all* procedures to be used on human subjects with a description of those *you* consider beyond already established and accepted techniques.

a.	Administration of proportional reasoning test	(30 min.)
b.	Administration of verbal-visual test	(20 min.)
c.	Administration of math anxiety test	(20 min.)
d.	NSTA-ACS Chemistry Achievement test	(40 min.)
e.	8 study guides of instruction (1 period each)	

a,b,c. These are all written, multiple choice type tests found in the current literature that will be administered at the onset of school.

d. A rational written chemistry exam commonly administered by chemistry teachers.

e. Problem solving instruction booklets-similar to those many teachers would prepare themselves.

3. State any potential risks - physical, psychological, social, legal, or other - connected with the proposed procedures and state means (including confidentiality safeguards) of protecting against or minimizing potential risks and an assessment of their likely effectiveness. If you consider the subject to be "at risk," in what respect do the potential benefits to the subject or contributions to the general body of knowledge outweigh the risks?

None - nothing out of ordinary.

4. Informed Consent

A. State how you will obtain documentation of informed consent. Answer even if you consider subjects not at risk. Do not use "inapplicable."

Students and parents will be asked to sign a written consent form. Permission of approporiate school officials will be obtained before school selection.

B. If you consider the subject to be "at risk," state exactly what you tell him or her in lay language to obtain informed consent per items 1-7 relative to each procedure wherein he or she is "at risk." This must be a form that is given or read to the subject particularly for this purpose. PLEASE ATTACH COPY OF FORM.

RETURN COMPLETED FORMS TO:

DR. PAUL H. GEBHARD
Chairperson of IUB Committee
for the Protection of Human Subjects
Institute for Sex Research
Morrison Hall 416

DEFINITIONS

SCIENTIFIC RESEARCH is a formal investigation designed to develop or contribute to generalizable knowledge.

HUMAN SUBJECT is a person about whom an investigator (professional or student) conducting scientific research obtains (1) data through intervention or interaction with the person, or (2) identifiable private information.

SUBJECT AT RISK means any individual who may be exposed to the possibility of injury, including physical, psychological, or social injury, as a consequence of participation as a subject in any research, development, or related activity which departs from the application of those established and accepted methods necessary to meet his or her needs, or which increases the ordinary risks of daily life, including the recognized risks inherent in a chosen occupation or field of service.

INFORMED CONSENT means the knowing consent of an individual or his or her legally authorized representative, so situated as to be able to exercise free power of choice without undue inducement or any element of force, fraud, deceit, duress, or any other form of constraint or coercion.* The basic elements of information necessary to such consent include:

(1) A fair explanation of the procedures to be followed, and their purposes, including identification of any procedures which are experimental. The explanation must be in language understandable by the subject.

(2) A description of any attendant discomforts and risks reasonably to be expected and safeguards to be used;

(3) A description of any benefits reasonably to be expected;

(4) A disclosure of any appropriate alternative procedures that might be advantageous for the subject;

(5) An offer to answer any inquiries concerning the procedures;

(6) An instruction that the person is free to withdraw his or her consent and to discontinue participation in this project or activity at any time without prejudice to the subject; and

(7) With respect to biomedical or behavioral research which may result in physical injury, an explanation as to whether compensation and medical treatment is available if physical injury occurs and, if so, what it consists of or where further information may be obtained.

---

*Deception may be used as part of an experiment if the sought-for data can be obtained in no other way. In obtaining informed consent the subjects should be told that the experiment cannot be fully described in advance lest their responses be altered, but that a description will be given them at the conclusion of the experiment. Deception, if used, must be a part of the experimental design and not a means of obtaining subjects' participation.

DEFINITIONS taken from: *The Institutional Guide to DHEW Policy on Protection of Human Subjects*, DHEW Publication No (NIH) 72-102, December 1, 1971; and the *Federal Register*, Vol. 43, No. 214, November 3, 1978. For further information consult the *Manual for Members of Insitutional Review Boards* which is available from the IUB Committee or the Office of Research and Graduate Development.

COMMITTEE APPROVAL

1. __________
2. __________
3. __________

Requires approval by Campus Committee prior to project initiation

☐ yes ☐ no

Date __________

COMMITTEE USE ONLY

437

1. __________
2. __________
3. __________
4. __________
5. __________
6. __________
7. __________
8. __________
9. __________

Indiana University / Bloomington Campus

Committee for the Protection of Human Subjects

DOCUMENTATION OF REVIEW AND APPROVAL
of
Research Project Utilizing Human Subjects

PROJECT TITLE: Facilitating Problem Solving in High School Chemistry

AGENCY GRANT NUMBER (IF KNOWN): __________

As the signature below testifies, the principal investigator(s) is pledged to conform to the following precepts:

> *As one engaged in investigation utilizing human subjects, I acknowledge the rights and welfare of the human subject or patient involved.*
>
> *I acknowledge my responsibility as an investigator to secure the informed consent of the subject by explaining the procedures, in so far as possible, and by describing the risks as weighed against the potential benefits of the investigation.*
>
> *I am in agreement with the Indiana University Statement of Principles Regarding the Use of Human Subjects in Research. I understand that in research a fundamental distinction must be recognized between research in which the aim is essentially therapeutic for a patient, and research, the essential object of which is purely scientific and without therapeutic value to the person subjected to the research.*
>
> *If there is reason for me to deviate from these precepts, I will seek prior approval in writing from the Bloomington Campus Committee for the Protection of Human Subjects.*

TYPED NAME(S): Dorothy L. Gabel
Robert D. Sherwood

Principal Investigator(s) or Project Director

SIGNATURE(S): __________ DATE: [illegible]

CHECK LIST FOR PRINCIPAL INVESTIGATOR:

☑ FORMS COMPLETED (ALL spaces filled in)
☑ FORMS SIGNED (ALL signature spaces)
☑ COPY OF PROPOSAL ATTACHED
☑ LETTER OF INFORMED CONSENT ATTACHED

This protocol for use of human subjects has been reviewed and approved by the Indiana University Bloomington Campus Committee for the Protection of Human Subjects.

__________ CHAIRPERSON OF IUB COMMITTEE

__________ DATE

APPENDIX B

Aptitude Instruments and Item Analyses

Proportional Reasoning Test. 439

Proportional Reasoning Test Administration Directions. 446

Proportional Reasoning Test Item Analysis. 447

Verbal-Visual Preference Test. 448

Verbal-Visual Preference Test Administration Directions. 454

Verbal-Visual Preference Test Item Analysis. 455

Mathematics Anxiety Test 456

Mathematics Anxiety Test Administration Directions. 463

Mathematics Anxiety Test Item Analysis. 464

Proportional Reasoning Test

General Directions

This is a test of certain understandings, skills and abilities that you have gradually developed. The total number of correct answers that you mark will be your score. Wrong answers will not be counted against your score. Try to answer all the questions. If a question seems too hard, make the best guess you can.

Use the special pencil to mark your answers on the separate answer sheet. Do not mark on the test booklet. Each question has only one best answer. Mark only one answer for each question. To change an answer, erase your first mark completely. Use the scratch paper provided.

Problem tasks for you to solve will be presented on the television screen. When you are told to begin, watch the television screen carefully. Then answer the questions in the booklet connected with the demonstrated task. Stop when you see the word "STOP" below the question you just answered. Wait for further directions from the person giving the test.

STOP. DO NOT TURN THE PAGE UNTIL YOU ARE TOLD TO.

Directions: Part I - III

Carefully watch the TV screen as the problem task is presented.

Then read each question carefully and decide which one of the four possible answers is the correct or best one.

Look on your answer sheet to find the row of boxes which has the same number as the question. In this row, mark the box having the same letter as the answer you have chosen.

Example

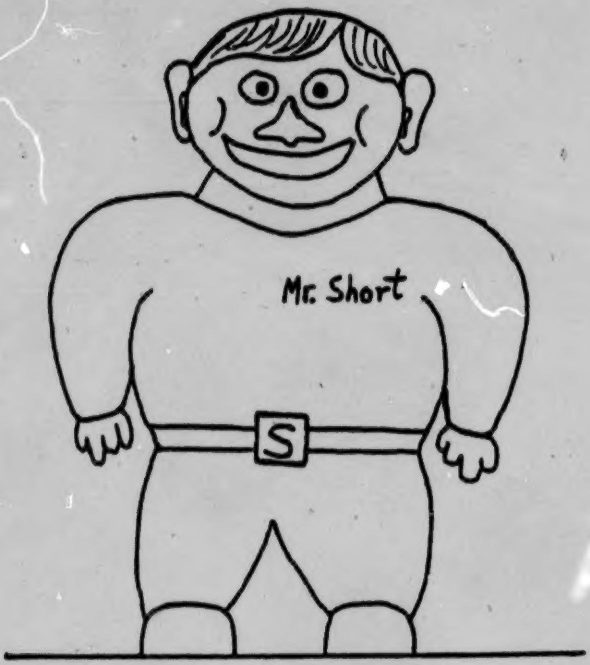
A closed figure having all four sides equal is a

A) triangle
B) rectangle
C) square
D) parallelogram

The correct answer to this question is lettered C, so you should mark box C if this question were on the test.

STOP. DO NOT TURN THIS PAGE UNTIL YOU ARE TOLD TO.

PART I



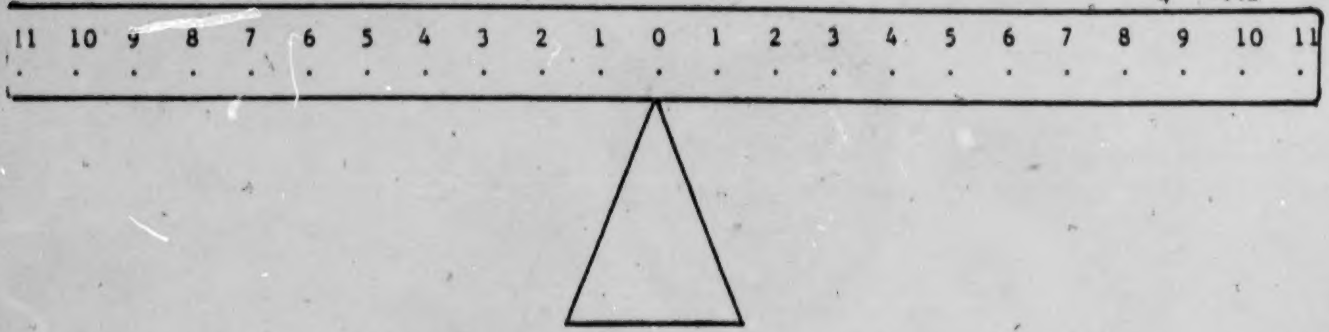
Meet Mr. Short

1. What is the relation between the two paper clip chains?
   - A) 5 small paper clips laid end-to-end are the same length as 3 big paper clips laid end-to-end.
   - B) 3 small paper clips laid end-to-end are the same length as 5 big paper clips laid end-to-end.
   - C) the big and the small paper clips are the same length.
   - D) not sure.

2. Mr. Short is 6 big paper clips tall. Mr. Tall is 9 big paper clips tall. Mr. Short is also 10 small paper clips tall. What is Mr. Tall's height in small paper clips?
   - A) 12
   - B) 13
   - C) 15
   - D) 16

3. Which method is most like the one you used to find the answer in question 2?
   - A) estimated guess
   - B) addition and/or subtraction
   - C) addition and/or subtraction along with multiplication and/or division
   - D) multiplication and/or division

STOP. DO NOT GO ON UNTIL TOLD TO.



4. No weight is hung on either side of the center point (fulcrum). What will be the position of the beam?
   A) The right end will tilt down.
   B) The beam will be balanced.
   C) The left end will tilt down.
   D) Not sure.

5. Weight is placed on one side of the beam. Can you rebalance the beam?
   A) Yes. Add weight on the side opposite the first weight.
   B) Yes. Add weight on the same side as the first weight.
   C) No.
   D) Not sure.

6. A 10 gram weight is placed at point 6 on the left side of the beam. How can the beam be balanced?
   A) Hang a 6 gram weight at point 10 on the right side of the beam.
   B) Hang a 10 gram weight at point 10 on the right side of the beam.
   C) Hang a 20 gram weight at point 6 on the right side of the beam.
   D) Not sure.

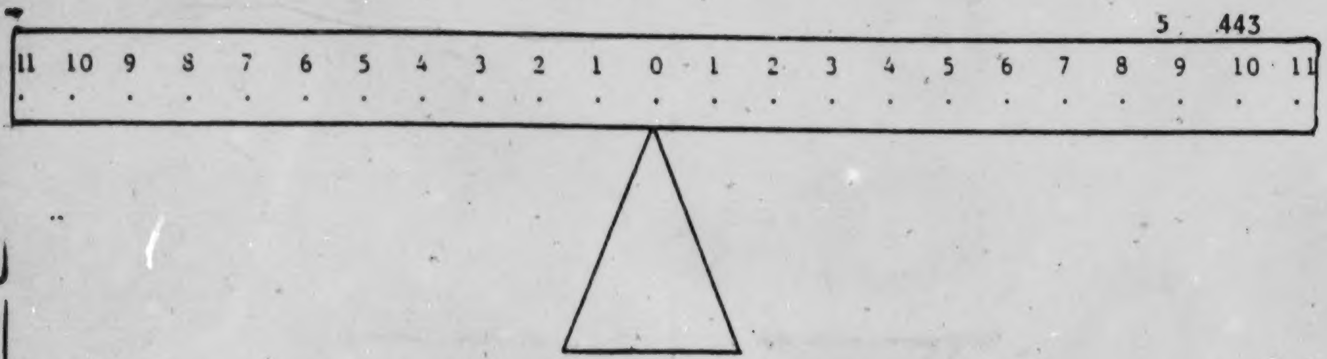
7. Which reason best matches the reason for your answer to question 6?
   A) 10 x 6 = 6 x 10.
   B) Left side: 10 + 6 = Right side: 6 + 10.
   C) Lighter weight must be placed farther from the center.
   D) None of the above.

8. An 8 gram weight is placed at point 6 on the left side of the beam. Where should you place 12 grams of weight to balance the beam?
   A) at point 7 on the right side
   B) at point 4 on the right side
   C) at point 2 on the right side
   D) at point 1 on the left side

9. Which reason best matches the reason for your answer to question 8?
   A) 8 + 6 = 14, 2 + X = 14, X = 2.
   B) 8 x 6 = 48, 12 x X = 48, X = 4.
   C) Heavier weights must be placed closer to the center.
   D) None of the above.

GO ON TO THE NEXT PAGE.

5 .443

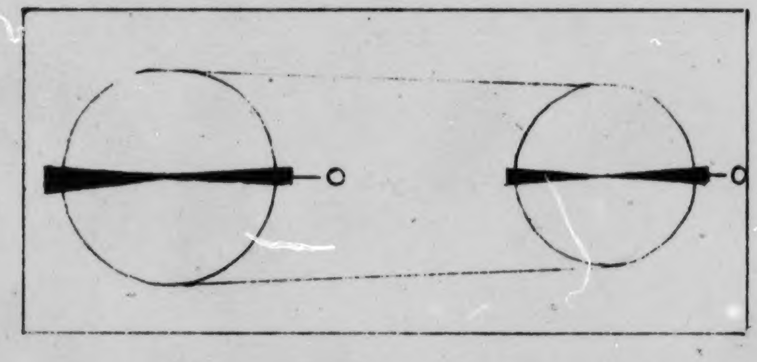


10. A 4 gram weight is placed at point 2. A 6 gram weight is placed at point 4. Both weights are on the left side of the beam. Where should you place an 8 gram weight on the right side to balance the beam?
   A) at point 2
   B) at point 4
   C) at point 6
   D) at point 8

11. Which reason best matches the reason for your answer to question 10?
   A) (4 x 2) + (6 x 4) = 8X, then X = 4.
   B) Heavier weights must be placed closer to the center.
   C) (4 + 2) + (6 + 4) = 8 + X, then X = 8.
   D) None of the above.

STOP. DO NOT GO ON UNTIL TOLD TO.

Part II



12. What is the relationship between the number of turns made by the small disk compared to the number of turns made by the large disk?
    - A) The small disk turns seven times when the large disk turns five times.
    - B) They both turn the same number of times.
    - C) The small disk turns five times when the large disk turns seven times.
    - D) Not sure.

13. If the small disk turned 14 times, how many times would the large disk turn?
    - A) 7
    - B) 10
    - C) 12
    - D) 16

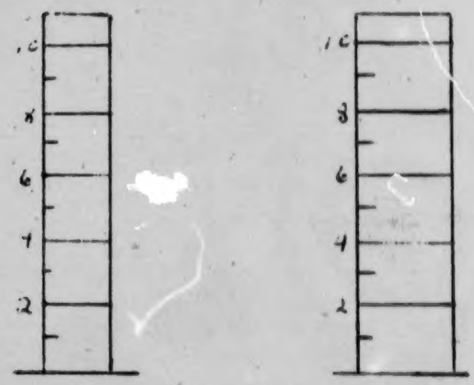
14. Which method is most like the one you used to find the answer in question 13?
    - A) estimated guess
    - B) addition and/or subtraction
    - C) addition and/or subtraction along with multiplication and/or division
    - D) multiplication and/or division

15. If the large disk turned 2 6/7 times, how many times would the small disk turn?
    - A) 3
    - B) 4 6/7
    - C) 4
    - D) 5 3/5

16. Which method is most like the one you used to find the answer in question 15.
    - A) estimated guess
    - B) addition and/or subtraction
    - C) addition and/or subtraction along with multiplication and/or division
    - D) multiplication and/or division

STOP. DO NOT GO ON UNTIL TOLD TO.

Part III



17. What is the relationship between the height of water in the two cylinders?
    A) the water rises six units in the wider cylinder and four units in the narrower cylinder.
    B) the water rises four units in the wider cylinder and six units in the narrower cylinder.
    C) the water rises the same in both the wide and narrow cylinders.
    D) Not sure.

18. Suppose that a new sample of water rose six units in the wide cylinder. How far would it rise in the narrow cylinder?
    A) 4
    B) 6
    C) 8
    D) 9

19. Which method is most like the one you used to find the answer in question 18?
    A) estimated guess
    B) addition and/or subtraction
    C) addition and/or subtraction along with multiplication and/or division
    D) multiplication and/or division

20. Suppose a new sample of water rose ten units in the narrow cylinder. How far would it rise in the wide cylinder?
    A) 6 2/3
    B) 8
    C) 9 1/2
    D) 15

21. Which method is most like the one you used to find the answer in question 20?
    A) estimated guess
    B) addition and/or subtraction
    C) addition and/or subtraction along with multiplication and/or division
    D) multiplication and/or division

STOP. THIS IS THE END OF THE TEST.

Piagetian Proportional Reasoning Test

Directions for Administration

PPRT is a three part test which attempts to measure the presence of the Piagetian mental schema of proportional reasoning. Instructions to be read aloud to the subjects are in capital letters. Instructions only for the examiner are in regular type.

1. Have students seated in the examination room. After making introductory remarks, say: I WILL NOW HAND OUT ALL TESTING MATERIALS. DO NOT OPEN YOUR TEST BOOKLET UNTIL TOLD TO. YOU SHOULD EACH HAVE A TEST BOOKLET, ANSWER SHEET, A #2 LEAD PENCIL, AND SCRATCH PAPER.
2. Distribute the test booklets, answer sheets, pencils, and scratch paper.
3. Have the students write their name at the top of the name grid and fill in the name grid.
4. Say: READ SILENTLY THE GENERAL DIRECTIONS WHILE I READ THEM ALOUD. After reading the directions, say: ARE THERE ANY QUESTIONS?
5. Say: TURN TO THE NEXT PAGE AND READ THE DIRECTIONS FOR PARTS I-IV SILENTLY WHILE I READ THEM ALOUD. After reading the directions, say: ARE THERE ANY QUESTIONS?
6. Play the example demonstration on the TV monitor and have the subjects answer the example question.
7. Say: REMEMBER: THIS IS AN UNTIMED TEST. WORK QUICKLY AND DO THE BEST YOU CAN. YOU ARE NOT PENALIZED FOR GUESSING.
8. Say: NOW YOU ARE READY FOR PART I. CAREFULLY WATCH THE TV MONITOR AS THE PROBLEM TASK IS PRESENTED.
9. Play the Part I task. Then say: TURN THE PAGE AND BEGIN.
10. When all students have completed questions 1-3, play the second section of the task for Part I. Then say: TURN THE PAGE AND ANSWER QUESTIONS 4 THROUGH 11 THEN STOP.
11. When all students have answered question 11, play the Part II task on the TV monitor. Then say: TURN THE PAGE AND BEGIN. STOP AT THE END OF PART II WHEN YOU SEE THE WORD STOP.
12. When all students have finished Part II, play Part III and say: TURN THE PAGE AND BEGIN. STOP WHEN YOU HAVE COMPLETED PART III.
13. Either collect all test materials from students as they finish or collect them when all students are done.

Item Analysis Proportional Reasoning Test

	Response Percentage				
Item	A	B	C	D	Blank
1	98.0*	.8	.6	.6	--
2	1.2	17.7	79.4*	1.8	--
3	4.6	26.8	16.9	51.4*	.4
4	2.6	97.2*	0.2	--	--
5	95.4*	2.4	2.0	.2	--
6	88.3*	7.1	1.4	3.2	--
7	36.7*	23.4	30.0	9.5	.4
8	4.6	56.2*	38.1	1.0	.2
9	18.5	42.9*	29.0	9.3	.4
10	6.0	41.7*	20.6	31.2	.6
11	38.5*	8.1	30.4	22.6	.4
12	99.0*	.6	.2	.2	--
13	1.2	84.1*	12.7	2.0	--
14	3.8	27.6	11.1	57.3*	--
15	16.7	38.3	34.3*	10.3	.4
16	31.2	23.2	15.9	29.2*	.6
17	3.2	95.4*	1.0	.2	.2
18	4.0	1.6	49.0	45.2*	.2
19	7.7	41.7	12.1	38.1*	.4
20	44.2*	47.0	3.2	5.0	.6
21	13.5	13.5	13.5	33.7*	1.6

N=504
*Correct Answer

Verbal-Visual Test

INSTRUCTIONS

The statements on the following pages represent ways of thinking, studying and problem solving, which are true for some people and not for others. Read each statement and decide whether or not it is true with respect to yourself, then indicate your answer on the separate answer sheet.

If you agree with the statement or decide that it does describe you, answer TRUE by marking in the circle below the letter A. If you disagree with the statement or feel that it is not descriptive of you, answer FALSE by marking in the circle below the letter B. Answer the statements as carefully and honestly as you can. The statements are not designed to assess the goodness or badness of the way you think. They are attempts to discover the methods of thinking you consistently use in various situations. There are no right or wrong answers.

In marking your answers on the answer sheet, be sure that the number that you are answering is the same as the number on the answer sheet.

Answer every statement either true (A), or false (B), even if you are not completely sure of your answer. If there are any questions, please raise your hand.

1. I have no difficulty in expressing myself verbally.

2. Listening to someone recount his experiences does not usually arouse mental pictures of the incidents being described.

3. When reading fiction I usually form a mental picture of a scene or room that has been described.

4. Essay writing is difficult for me.

5. By using mental pictures of the elements of a problem, I am often able to arrive at a solution.

6. I enjoy being able to rephrase my thoughts in many ways for variety's sake when both writing and speaking.

7. I tell jokes and stories poorer than most people.

8. I enjoy doing work that requires the use of words.

9. My day dreams are sometimes so vivid I feel as though I actually experience the scene.

10. I often use mental pictures to solve problems.

11. I find it difficult to find enough synonyms or alternate forms of a word when writing.

12. I have difficulty expressing myself in writing.

13. My knowledge and use of grammar needs improvement.

14. I would rather work with ideas than words.

15. I enjoy learning new words and incorporating them into my vocabulary.

16. I do not have a vivid imagination.

17. I can easily picture moving objects in my mind.

18. I can form mental pictures to almost any word.

19. I have only vague visual impressions of scenes I have experienced.

20. I can easily think of synonyms for words.

21. I think that most people think in terms of mental pictures whether they are completely aware of it or not.

22. I am able to express my thoughts clearly.

23. I consider myself a fast reader.

24. I have a large vocabulary.

25. I find it easy to visualize the faces of people I know.

26. My marks have been hampered by inefficient reading.

27. It bothers me when I see a word used improperly.

28. I am fluent at writing essays and reports.

29. I can close my eyes and easily picture a scene I have experienced.

30. When someone describes something that happens to him, I sometimes find myself vividly imagining the events that happened.

31. When I hear or read a word, a stream of other words often comes to mind.

32. I read rather slowly.

33. I am usually able to say what I mean in my first draft of an essay or letter.

34. I never use mental pictures or images when trying to solve problems.

35. Studying the use and meaning of words has become a habit with me.

36. I speak or write what comes into my head without worrying greatly about my choice of words.

37. I find it difficult to form a mental picture of anything.

38. My dreams are extremely vivid.

39. I have better than average fluency in using words.

40. I read a great deal.

41. I am continually aware of sentence structure.

42. My thinking often consists of mental pictures or images.

43. I do not form a mental picture of people or places when reading of them.

44. I often have difficulty in explaining things to others.

45. My daydreams are rather indistinct and hazy.

46. I often enjoy the use of mental pictures to reminisce.

47. I often use mental images or pictures to help me remember things.

48. When remembering a scene I use verbal descriptions rather than mental pictures.

49. I take great pains to express myself with precision and accuracy in both verbal speech and written work.

50. I have difficulty producing associations for words.

51. I often have ideas that I have trouble expressing in words.

52. Just before falling asleep I often find myself picturing events that have happened.

53. I am a good story teller.

54. I spend very little time attempting to increase my vocabulary.

Modified Verbal-Visual Questionnaire

Directions for Administration

VVQ is a series of agree-disagree statements which attempts to measure subjects preference for either verbal (low score) or visual (high score) encoding of information. Instructions to be read aloud to subjects are in capital letters. Instructions only for the examiner are in regular type.

1. Have students seated in the examination room. After making introductory remarks, say: I WILL NOW HAND OUT ALL TESTING MATERIALS. DO NOT OPEN YOUR TEST BOOKLET UNTIL TOLD TO. YOU SHOULD EACH HAVE A TEST BOOKLET, ANSWER SHEET, AND A #2 LEAD PENCIL.
2. Distribute the test booklets, answer sheets, and pencils.
3. Have the students write their name at the top of the name grid and fill in the name grid.
4. Say: READ SILENTLY THE INSTRUCTIONS WHILE I READ THEM ALOUD. After reading the instructions say: ARE THERE ANY QUESTIONS?
5. If no questions, have the students turn the page and begin. Collect materials as students finish.

Item Analysis Verbal-Visual Preference Test

Item-Type**		Response Percentage A	B	C
1	Ve	56.3	43.3*	.4
2	Vi	15.3	84.7*	--
3	Vi	93.8*	6.2	--
4	Ve	52.0*	47.8	.2
5	Vi	61.7*	38.1	.2
6	Ve	69.6	30.0*	.4
7	Ve	29.8*	70.2	--
8	Ve	43.8	56.2*	--
9	Vi	61.7*	38.3	--
10	Vi	66.3*	33.7	--
11	Ve	44.8*	55.2	--
12	Ve	36.9*	63.1	--
13	Ve	74.4*	25.4	.2
14	Ve	77.6*	22.4	--
15	Ve	73.6	26.2*	.2
16	Vi	14.1	85.9*	--
17	Vi	84.7*	15.3	--
18	Vi	59.5*	40.5	--
19	Vi	16.3	83.7*	--
20	Ve	49.4	50.6*	--
21	Vi	89.5*	10.5	--
22	Ve	55.4	44.6*	--
23	Ve	48.2	51.8*	--
24	Ve	46.6	53.4*	--
25	Vi	86.5*	13.5	--
26	Ve	24.8*	75.2	--
27	Ve	55.0	45.0*	--
28	Ve	30.8	68.8*	.4
29	Vi	92.1*	7.7	.2
30	Vi	81.9*	17.9	.2
31	Ve	46.6	53.2*	.2
32	Ve	27.0*	72.8	.2
33	Ve	56.5	43.1*	.4
34	Vi	8.9	90.9*	.2
35	Ve	22.4	77.2*	.4
36	Ve	39.9*	59.9	.2
37	Vi	2.6	97.2*	.2
38	Vi	71.0*	28.8	.2
39	Ve	55.4	44.4*	.2
40	Ve	49.4	50.0*	.6
41	Ve	28.0	71.6*	.4
42	Vi	80.8*	19.0	.2
43	Vi	7.5	92.3*	.2
44	Ve	31.5*	97.9	.6
45	Vi	22.2	77.6*	.2
46	Vi	90.9*	8.7	.4
47	Vi	90.1*	9.5	.4
48	Vi	18.5	80.6*	1.0
49	Ve	35.9	63.5*	.6
50	Ve	30.8*	68.5	.8
51	Ve	53.4*	45.8	.8
52	Vi	87.3*	11.9	.8
53	Ve	50.2	48.2*	1.6
54	Ve	48.0*	48.8	3.2

N=304
* "Correct" Answer for maximum visual score
** Vi for Visual Items (23), Ve for Verbal Items (31)

PAGES 456-462 "MATHEMATICS ANXIETY RATING SCALE (MARS)"
REMOVED DUE TO COPYRIGHT RESTRICTIONS.

Directions for Administration: Mathematics Anxiety Rating Scale (MARS).

1. Pass out Answer Sheets, and have students fill in the name section (Last, First, Middle Initial).

2. Please have the students fill in the K section under Special Codes with your number code (listed below). (See Sample)

3. Pass out the test booklets and have the students read the instructions on top. Please do not have them write on the test booklet.

4. The instructions at the top of the page have the phrase "you are frightened by it nowdays." By "frightened" we mean "do not like to do it at all" or "become anxious or upset when doing it."

5. While there are several items, it should only take about 20 minutes to complete the test.

Item Analysis Mathematics Anxiety Test

Item	Response Percentage				
	A	B	C	D	Blank
1	58	30	9	2	8
2	36	37	15	9	3
3	36	35	18	7	4
4	33	40	18	7	4
5	89	8	2	1	1
6	53	30	11	4	2
7	50	27	15	5	3
8	50	27	15	4	4
9	29	37	24	7	3
10	50	29	12	7	3
11	38	30	17	8	6
12	60	26	11	2	1
13	61	28	8	2	1
14	92	5	1	1	0
15	26	27	23	12	12
16	60	24	10	5	1
17	62	20	10	5	3
18	53	28	13	3	4
19	61	22	11	4	2
20	47	29	13	8	4
21	70	17	9	2	2
22	67	24	7	1	1
23	72	16	6	3	4
24	64	24	8	2	2
25	67	22	6	3	3
26	55	28	9	4	4
27	50	31	14	3	2
28	67	20	4	3	4
29	50	30	13	5	2
30	86	10	3	0	0
31	56	30	10	3	1
32	19	29	29	14	9
33	33	30	22	9	6
34	31	32	20	10	7
35	51	31	11	4	2
36	60	24	9	4	3
37	72	18	6	2	2
38	77	15	6	1	1
39	74	18	4	1	2
40	40	33	15	8	4
41	39	33	16	7	5
42	57	27	11	3	2
43	17	27	27	12	17
44	41	35	17	4	2
45	44	29	13	8	5
46	53	30	72	4	1
47	77	17	4	1	1
48	69	23	6	2	1
49	49	34	13	2	2
50	40	37	16	5	3
51	25	42	18	7	8
52	39	30	21	7	4
53	26	38	17	12	6
54	12	25	26	14	22
55	69	21	7	3	1
56	67	23	6	3	1
57	42	32	16	7	3
58	42	37	14	5	2
59	63	23	10	3	1
60	69	23	5	2	1

Item Analysis Mathematics Anxiety Test
(continued)

	Response Percentage				
Item	A	B	C	D	Blank
61	16	34	26	14	10
62	59	25	10	4	2
63	48	32	14	4	2
64	50	30	13	5	1
65	47	32	15	4	2
66	39	31	18	8	5
67	80	15	5	0	0
68	84	12	3	1	0
69	83	13	4	1	0
70	69	22	7	2	0
71	58	28	9	3	2
72	16	38	24	13	10
73	40	34	13	9	4
74	20	32	23	12	14
75	19	24	23	14	21
76	18	23	18	15	26
77	18	38	26	10	8
78	34	31	19	10	6
79	14	24	23	18	21
80	81	10	6	2	1
81	55	25	12	5	3
82	33	39	16	9	3
83	53	28	12	4	3
84	12	32	29	16	12
85	26	26	22	12	14
86	38	32	19	8	4
87	52	30	12	4	1
88	47	30	15	7	2
89	52	26	14	6	2
90	53	28	13	4	1
91	18	30	24	15	13
92	54	24	15	5	2
93	68	20	9	2	1
94	35	37	20	6	2
95	50	29	12	7	3
96	33	36	18	8	5
97	62	25	10	2	1
98	65	21	8	4	2

N = 553

APPENDIX C

Reviewer's Comments

Dependent Measures. 467
Instruction 471

REVIEWERS COMMENTS ON DEPENDENT MEASURES

The reviewers evaluated the quizzes and tests at the same time as they evaluated the instructional units. Overall directions for reviewing are given in Appendix A.

Questions (Q) and Responses (R) for Moles Quizzes and Tests.

I. Quizzes: (On each quiz, two items may measure the same objective. One item will involve decimals whereas the other uses whole numbers. We thought we would check to see if there are any differences.)

(Q) a. If there are any quiz items that do not match the stated objectives, please list the number of the item.

(R1) O.K.

(R2) None.

(Q) b. If there are any quiz items with content errors, please note item and error.

(R1) O.K.

(R2) None.

II. Test

(Q) a. Do you think the test adequately samples the objectives of the unit?

(R1) For the length of the test, it is fine. I think there are some common misconceptions or errors which aren't checked by any of the items, but the objectives are sampled.

(R2) Much more than adequate--coverage is excellent.

(Q) b. Each test contains one or more items that we consider to be transfer items. Please select any you consider to be in this category.

(R1) (Note: Response has been summarized because of length) I'm not sure that any of them are but I'm reasonably confident that items 4 and 9 are the ones you have in mind. Other transfer items are possible that might be better.

(R2) #4, 9.

REVIEWERS COMMENTS ON
DEPENDENT MEASURES

The reviewers evaluated the quizzes and tests at the same time as they evaluated the instructional units. Overall directions for reviewing are given in Appendix A.

Questions (Q) and Responses (R) for Gas Laws Quizzes and Test.

I. Quizzes (On each quiz, two items may measure the same objective. One item will involve decimals whereas the other uses whole numbers. We thought we would check to see if there are any differences).

(Q) a. If there are any quiz items that do not match the stated objectives, please list the number of the item.

(R1) No response.

(R2) None.

(Q) b. If there are any quiz items with content errors, please note them and the error.

(R1) No response.

(R2) None.

II. Test

(Q) a. Do you think the test adequately samples the objectives of the unit?

(R1) Yes.

(R2) Yes, there is excellent coverage of the objectives.

(Q) b. Each test contains one or more items that we consider to be transfer items. Please select any you consider to be in this category.

(R1) I like #3 because they now need to use the same logic to derive a relationship showing P related to T with V constant. They may simply say $\frac{P_1\cancel{V_1}}{T_1} = \frac{P_2\cancel{V_2}}{T_2}$ canceling the V_1 and V_2, in which case little or no transfer is involved. #6 and #10 involve transfer of concepts from the mole unit to this unit.

(R2) #6 and #10.

REVIEWERS COMMENTS ON DEPENDENT MEASURES

The reviewers evaluated the quizzes and tests at the same time as they evaluated the instructional units. Overall directions for reviewing are given in Appendix A.

Questions (Q) and Responses (R) for Stoichiometry Quizzes and Test.

I. Quizzes (On each quiz, two items may measure the same objective. One item will involve decimals whereas the other uses whole numbers. We thought we would check to see if there are any differences).

(Q) a. If there are any quiz items that do not match the stated objectives, please list the number of the item.

(R1) No response.

(R2) None.

(Q) b. If there are any quiz items with content errors, please note them and the error.

(R1) S-I-QP-1, #4 doesn't exactly have an error but mentioning STP for the CO_2 but not indicating T and P for the other gases could be misleading. Are only two choices intended? Where is the correct answer?

(R2) S-I-QP-1, question 4. Only two of the four alternatives are listed and the correct one is not among them (A, B listed; C, D not shown). (Note: This error was corrected before student use.)

II. Test

(Q) a. Do you think the test adequately samples the objectives of the unit?

(R1) Yes.

(R2) No response.

(Q) b. Each test contains one or more items that we consider to be transfer items. Please select any you consider to be in this category.

(R1) #5 and #9 (I predict students will do poorly on them).

(R2) #5, 9, 10.

REVIEWERS COMMENTS ON DEPENDENT MEASURES

The reviewers evaluated the quizzes and tests at the same time as they evaluated the instructional units. Overall directions for reviewing are given in Appendix A.

Questions (Q) and Responses (R) for Molarity Quizzes and Test.

I. Quizzes (On each quiz, two items may measure the same objective. One item will involve decimals whereas the other uses whole numbers. We thought we would check to see if there are any differences).

(Q) a. If there are any quiz items that do not match the stated objectives, please list the number of the item.

(R1) No response.

(R2) None.

(Q) b. If there are any quiz items with content errors, please note them and the error.

(R1) No response.

(R2) None.

II. Test

(Q) a. Do you think the test adequately samples the objectives of the unit?

(R1) Best you can do with 10 items but you covered a lot of material.

(R2) Yes.

(Q) b. Each test contains one or more items that we consider to be transfer items. Please select any you consider to be in this category.

(R1) #5, #7 and possibly #10. I expect the reasoning involved is different than what is used elsewhere in the unit but the skills seem to be the same.

(R2) #5 and #10. I selected #10 because different information is given to do the calculation compared to the objective #2 stated in lesson 3.

Note: In all cases where I chose items as transfer ones, I still feel that they match objectives reasonably well. I really liked the instructional materials. They were well planned and executed and the quizzes and unit tests are solid (face) measures of the material and transfer.

UNIT REVIEWER'S COMMENTS ON INSTRUCTION

INSTRUCTIONS (To Reviewers): Please read through the materials and answer the following questions. We are particularly interested in your comments on the content, rather than the method.

Questions (Q) and Responses (R): MOLES UNIT

I. TEACHER'S GUIDE

(Q) a. Are the objectives reasonable for the topic:

(R1) They look O.K. to me.

(R2) Yes.

(Q) b. Are the prerequisite skills adequate?

(R1) Well, they need to be able to read, write, and all that, but otherwise they look O.K.

(R2) Yes.

II. Instructional Materials

(Q) a. Is there adequate coverage of the topic?

(R1) No response.

(R2) Yes, very well done with many analogies within common experience (bricks) as the mole concept is developed.

(Q) b. Are any errors in chemistry present?

(R1) A few places where there may be confusion. I have indicated these (Lesson I).

(R2) I found none.

(Q) c. Does the unit appear to be matched with the objectives?

(R1) Yes.

(R2) Most definitely!

UNIT REVIEWER'S COMMENTS
ON INSTRUCTION

INSTRUCTIONS (To Reviewers): Please read through the materials and answer the following questions. We are particularly interested in your comments on the content, rather than the method.

Questions (Q) and Responses (R): GAS LAWS UNIT

I. TEACHER'S GUIDE

(Q) a. Are the objectives reasonable for the topic?

(R1) Yes.

(R2) Yes.

(Q) b. Are the prerequisite skills adequate?

(R1) Yes.

(R2) Yes. Although some students (even in chemistry) will need to learn how to calculate °K from °C and vice versa, this is easily taught.

II. Instructional Materials

(Q) a. Is there adequate coverage of the topic?

(R1) Depends on your point of view. The focus is on getting answers to problems rather than understanding the behavior of gases. I would prefer the latter but expect the former is dictated by the purposes of the research.

(R2) Yes, again, more than adequate - excellent. I really like the style.

(Q) b. Are any errors in chemistry present?

(R1) See Lesson 2.

(R2) A possible error exists, not in the chemistry, but in the definition of proportion in Lesson 1. $P_1V_1 = k = P_2V_2$ $P_1V_1 = P_2V_2$ is a proportion, but, at least, most high school students won't know that it is or isn't, because $P_1V_1 - P_2V_2$ can be $\frac{P_1V_1}{1} = \frac{P_2V_2}{1}$.

A proportion is the equality of 2 Ratios. However, in your lesson 1 you never make this clear how $P_1V_1 = P_2V_2$ is the equality of two ratios. Most students will simply view it as the equality of products. You could use $\frac{P_1}{P_2} = \frac{V_2}{V_1}$ but this presents a transition problem to the combined gas law lesson. $\frac{P_1}{P_2} = \frac{V_2}{V_1}$, however, is the clear statement of the equality of 2 ratios that students will recognize as such. In sum, what I am saying is that in lesson 1, you may not be teaching them by the proportional method, although you view it as such.

(Q) c. Does the unit appear to be matched with the objectives?

(R1) Yes.

(R2) Well matched.

UNIT REVIEWER'S COMMENTS
ON INSTRUCTION

INSTRUCTIONS (To Reviewers): Please read through the materials and answer the following questions. We are particularly interested in your comments on the content, rather than the method.

Questions (Q) and Responses (R): STOICHIOMETRY UNIT

I. TEACHER'S GUIDE

(Q) a. Are the objectives reasonable for the topic?

(R1) Yes.

(R2) Yes, they remind me of my years at NCHS.

(Q) b. Are the prerequisite skills adequate?

(R1) Yes.

(R2) Yes, although you list a prerequisite skill the ability to balance equations, you don't emphasize it in the unit.

II. Instructional Materials

(Q) a. Is there coverage of the topic?

(R1) Yes. (Too much?)

(R2) Excellent coverage.

(Q) b. Are any errors in chemistry present?

(R1) I didn't find any.

(R2) S-III-P-2 The equation $3H_2 + 2N_2 \rightarrow 2NH_3$ is not balanced! (A simple typo error.)

(Q) c. Does the unit appear to match with the objectives?

(R1) Yes.

(R2) Very well matched; no loose ends hanging.

UNIT REVIEWER'S COMMENTS ON INSTRUCTION

INSTRUCTIONS (To Reviewers): Please read through the materials and answer the following questions. We are particularly interested in your comments on the content, rather than the method.

Questions (Q) and Responses (R): MOLARITY UNIT

I. TEACHER'S GUIDE

(Q) a. Are the objectives reasonable for the topic?

(R1) Yes.

(R2) Yes, quite reasonable expectations.

(Q) b. Are the prerequisites skills adequate?

(R1) Lesson 2, they must know what a mole is and how to convert from mass to moles. (Other units cover this, of course).

(R2) Yes, you have considered what they should know before attempting the unit.

II. Instructional Materials

(Q) a. Is there adequate coverage of the topic?

(R1) No response.

(R2) Again, the instructional materials are excellently done.

(Q) b. Are any errors in chemistry present?

(R1) Yes, see comments on lessons.

(R2) I found none, except for a misspelled word on Mo-1-P-6 in the problem: Cobolt should be Cobalt.

(Q) c. Does the unit appear to be matched with the objectives?

(R1) Yes.

(R2) Well matched.

APPENDIX D

Dependent Measures and Item Analyses

Moles Immediate and Delayed Posttests 477

Gas Laws Immediate and Delayed Posttests. . . 484

Stoichiometry Immediate and Delayed Posttests 489

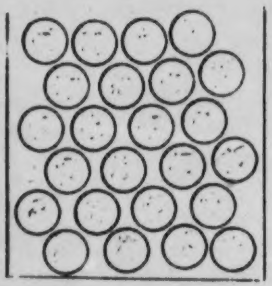
Molarity Immediate and Delayed Posttests. . . 496

ACS-NSTA Chemistry Achievement Test Regular 501

ACS-NSTA Chemistry Achievement Test Scrambled 504

Name________________________ Period or Small group________________________ Moles I - QA - 1

Please answer the following questions by circling the correct answer. In order to get full credit you must show your work for question 6. Remember, 1 mole = 6.02×10^{23} particles and that these problems are very similar to the use of dozen. Example, how many dozen oranges would be represented by 24 oranges?



$\frac{24 \text{ oranges}}{12 \text{ oranges/dozen}} = 2 \text{ dozen}$

1. Carbon tetrachloride has the formula CCl_4. How many moles of chlorine atoms (Cl) are in 3 moles of carbon tetrachloride?
   a. 3 moles
   b. 6.02×10^{23} moles
   c. 12 moles
   d. 24.08×10^{23} moles
2. How many atoms of aluminum (Al) are present in 3 moles of aluminum?
   a. 2.00×10^{23} atoms
   b. 6.02×10^{23} atoms
   c. 9.03×10^{23} atoms
   d. 18.06×10^{23} atoms
3. How many moles of calcium hydroxide $Ca(OH)_2$ correspond to 12.04×10^{23} molecules of $Ca(OH)_2$?
   a. 0.5 mole
   b. 2.0 moles
   c. 3.01×10^{23} moles
   d. 24.12×10^{23} moles

4. How many atoms of aluminum (Al) are present in 2.3 moles of Al?

   a. 0.382×10^{23} atoms

   b. 2.62×10^{23} atoms

   c. 13.85×10^{23} atoms

   d. 27.70×10^{23} atoms

5. How many atoms of chlorine (Cl) are present in 4.0 moles of carbon tetrachloride (CCl_4)?

   a. 1.51×10^{23} atoms

   b. 6.02×10^{23} atoms

   c. 24.08×10^{23} atoms

   d. 96.32×10^{23} atoms

6. How many moles of fluorine atoms (F) correspond to 18.06×10^{23} molecules of calcium fluoride CaF_2? (You must show your work to get full credit!)

   a. 3

   b. 6

   c. 18

   d. 36

Name: ______________________________

Period or ______________________________
small group

Please answer the following questions by circling the correct answer. In order to get full credit for question four you must show your work.

These problems are very similar to problems like that of the packing carton. Example: How many dozens of fruit can be stored in a box of 69 pints if each dozen has a volume of 3 pints?

$$\frac{69\ \cancel{\text{pints}}}{3\ \cancel{\text{pints}}/\text{dozen}} = 23\ \text{dozen}$$

Remember, just as in this example where 1 dozen = 3 pints for gases 1 mole = 22.4 liters at STP.

1. A sample of helium He contains 2 moles. How many liters would this gas occupy at STP?

   a. 0.089 liter
   b. 2.0 liters
   c. 11.2 liters
   d. 44.8 liters

2. How many moles are represented by 70 liters of fluorine gas (F_2) at STP?

   a. 0.32 mole
   b. 3.125 moles
   c. 70 moles
   d. 1589 moles

3. How many liters would 6.32 moles of oxygen gas (O_2) occupy at STP?

   a. 0.282 liter
   b. 3.54 liters
   c. 141.6 liters
   d. 283.1 liters

4. A sample of carbon dioxide gas (CO_2) measured at STP occupied 126.5 liters. How many moles of CO_2 were present in this sample? (Show your work!)

   a. 0.177 mole
   b. 5.65 moles
   c. 379.5 moles
   d. 2833.6 moles

Name:______________________________ Mole III - QA - 1

Period or Small group:____________

Please answer the following questions by circling the correct answer. You must show your work in order to recieve full credit for question 5. These problems are very similar to the situation of dozens of fruit. Example: If a dozen apples weighed 6000 grams how much would 4 dozens apples weigh?

$$4\ \cancel{\text{dozen}}\ \text{apples} \times \frac{6000\ \text{grams}}{\cancel{\text{dozen}}} = 24{,}000\ \text{grams apples}$$

Atomic masses you may wish to use:

Ca = 40.1

C = 12.0

O = 16

Na = 23.0

Kr = 83.8

Br = 79.9

Zn = 65.4

1. How many grams of sodium (Na) correspond to 3 moles of Na?

   a. 0.13 gram
   b. 7.67 grams
   c. 69.0 grams
   d. 32.0 grams

2. How many moles of krypton (Kr) gas correspond to 167.6 grams of Kr?

   a. 0.5 mole
   b. 2.0 moles
   c. 83.8 moles
   d. 335.2 moles

3. How much does 4.5 moles of sodium (Na) weigh?

   a. 0.20 gram
   b. 5.10 grams
   c. 23.0 grams
   d. 103.5 grams

4. A sample of calcium carbonate ($CaCO_3$) contains 3.6 moles. How much would this sample weigh?

   a. 27.8 grams
   b. 244.8 grams
   c. 360.4 grams
   d. 446.4 grams

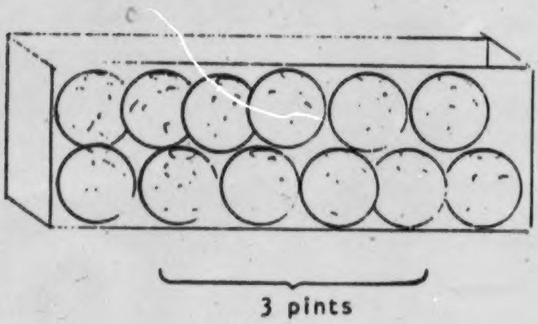
5. How many moles of zinc bromide ($ZnBr_2$) correspond to 200 grams of $ZnBr_2$.

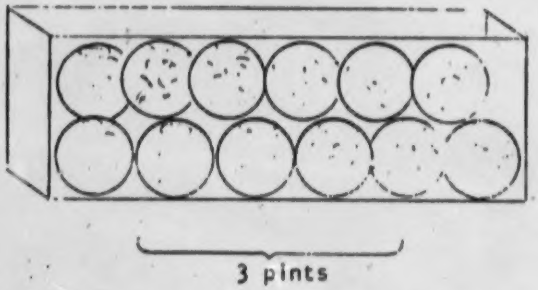
   a. 0.69 mole
   b. 0.89 mole
   c. 1.13 moles
   d. 1.38 moles

Name________________ Period or Samil Group ______

Moles IV-QA-1

Please answer the following questions by circling the correct answer. Remember, these problems maybe solved by using a method similar to the one used with fruit. Example: How much volume would 24 oranges occupy if each dozen orange occupies 3 pints? (See diagram). To get full credit for question six, you must show your work.





$$\frac{24\ \text{or}\cancel{\text{anges}}}{12\ \text{or}\cancel{\text{anges}}/\text{dozen}} = 2\ \text{dozen}$$

$$2\ \cancel{\text{dozen}} \times \frac{3\ \text{pints}}{\cancel{\text{dozen}}} = 6\ \text{pints}$$

You may need the following atomic masses: Ne = 20.2 Cu = 63.5 K = 39.1 N = 14.0 O = 16.0 C = 12.0 H = 1.0

1. What volume would 18.06×10^{23} atoms of neon gas (Ne) occupy at STP?

   a. 3.0 liters b. 7.47 liters

   c. 67.2 liters d. 404.5 liters

2. What would be the mass of one atom of copper (Cu)?

   a. 0.0026×10^{-23} gram b. 10.5×10^{-23} gram

   c. 63.5×10^{-23} gram d. 382.3×10^{-23} gram

3. What volume would 34.3×10^{23} atoms of neon (Ne) occupy at STP?

   a. 3.93 liters b. 127.6 liters

   c. 1348.5 liters d. 4625.3 liters

4. How many moles correspond to 303.3 grams of potassium nitrate (KNO_3)?

   a. 0.33 mole b. 2.35 moles

   c. 3.00 moles d. 4.39 moles

5. How many molecules of carbon dioxide (CO_2) are present in a sample of CO_2 that has a volume of 40.3 liters at STP?

   a. 5435 molecules b. 9.2×10^{21} molecules

   c. 3.35×10^{23} molecules d. 10.8×10^{23} molecules

6. A sample of ethane gas (C_2H_6) has a mass of 60 grams. What volume would this gas occupy at STP? (Be sure to show your work!)

   a. 11.2 liters b. 44.8 liters

   c. 80.4 liters d. 103.4 liters

Name: ______________________________ Moles-T-1

Period or small group: __________

MOLE TEST

Please answer the follwoing questions by circling the correct answer.

Constants and atomic masses that you will need are listed below.

1 mole = 6.02×10^{23} particles 1 mole = 22.4 liters at STP

Carbon (c) = 12.0 Hydrogen (H) = 1.0

Sulfur (S) = 32.1 Oxygen (O) = 16.0

Zinc (Zn) = 65.4 Helium (He) = 4.0 Xenon (Xe) = 131.3

1. How many moles of neon gas (Ne) correspond to 18.06×10^{23} atoms of neon?

A. 0.33 mole B. 1.24 moles

C. 3.0 moles D. 108.7 moles

2. How many moles of zinc (Zn) correspond to 163.5 grams of Zn?

A. 0.40 mole B. 2.50 moles

C. 1422 moles D. 10382 moles

3. How many molecules of methane (CH_4) are present in a sample of methane that contains 5.0 moles?

A. 0.83×10^{23} molecules B. 1.20×10^{23} molecules

C. 3.01×10^{23} molecules D. 30.1×10^{23} molecules

4. How much would the oxygen atoms weigh in a sample of CO_2 which contained 4.0 moles?

A. 8 grams B. 64 grams

C. 128 grams D. 176 grams

5. How many moles correspond to 16 liters of oxygen gas at STP?

A. 0.71 mole B. 1.4 moles

C. 2.0 moles D. 358.4 mole

6. How much would a sample of helium gas (He) weigh, if at STP its volume was 78.4 liters?

A. 0.07 gram B. 1.14 grams

C. 14.0 grams D. 313.6 grams

7. A sample of hydrogen sulfide (H_2S), has a mass of 68.2 grams. How many molecules of H_2S are present in this sample?

A. 6.20×10^{23} molecules B. 12.04×10^{23} molecules

C. 12.40×10^{23} molecules D. 410.6×10^{23} molecules

8. A sample of ethane gas (C_2H_6) has a volume of 100.8 liters at STP. How many molecules of ethane are present in the sample?

A. 1.34×10^{23} molecules B. 27.1×10^{23} molecules

C. 282.2×10^{23} molecules D. 375.1×10^{23} molecules

9. A sample of sulfur dioxide (SO_2) has a mass of 128.2 grams. How many atoms of oxygen (O) are present in this sample?

A. 3.02×10^{23} atoms B. 12.04×10^{23} atoms

C. 16.04×10^{23} atoms D. 24.08×10^{23} atoms

10. How much would 9.03×10^{23} atoms of xenon gas (Xe) weigh?

A. 87.5 grams B. 98.5 grams

C. 197.0 grams D. 1185.6 grams

Item Analysis for Moles

Immediate and Delayed Posttest

Measure-Item		Response Percentage				
		A	B	C	D	Blank
Quiz 1	1	10.6	3.3	66.6*	17.9	.9
Quiz 1	2	1.3	2.4	1.3	94.2*	.5
Quiz 1	3	3.5	86.9*	2.9	4.9	1.1
Quiz 1	4	5.5	3.5	87.8*	.9	1.3
Quiz 1	5	2.7	3.1	52.2	39.4*	1.5
Quiz 1	6	38.1	46.2*	4.7	4.4	3.1
Quiz 2	1	1.5	.4	1.6	95.8*	.2
Quiz 2	2	4.4	92.1*	.4	2.0	.4
Quiz 2	3	4.4	2.5	89.0*	3.1	.2
Quiz 2	4	2.5	92.0*	.9	2.2	1.5
Quiz 3	1	1.8	2.4	94.7*	.4	.2
Quiz 3	2	3.5	93.2*	1.6	.9	.2
Quiz 3	3	2.0	1.5	1.6	94.2*	.2
Quiz 3	4	4.7	4.2	87.4*	2.7	.4
Quiz 3	5	3.6	73.0*	15.3	5.5	2.0
Quiz 4	1	8.0	2.5	86.3*	1.8	0
Quiz 4	2	3.1	54.4*	23.2	17.0	.9
Quiz 4	3	5.1	89.6*	1.6	2.4	0
Quiz 4	4	3.6	5.1	79.7*	9.5	.5
Quiz 4	5	1.8	4.2	11.5	80.5*	.4
Quiz 4	6	4.7	80.7*	5.5	4.7	2.5
Test	1	.9	.7	95.4*	2.5	.2
Test	2	1.8	93.1*	2.0	2.2	.7
Test	3	6.2	1.8	9.3	82.3*	.2
Test	4	8.4	15.3	52.2*	22.6	1.1
Test	5	75.0*	6.6	2.2	15.1	.9
Test	6	2.5	7.1	77.9*	10.8	1.5
Test	7	3.1	70.6*	7.5	17.7	.7
Test	8	5.3	82.3*	4.6	4.4	3.3
Test	9	9.1	37.4	7.5	42.3*	3.5
Test	10	4.6	3.8	58.6*	6.9	25.7

* Correct answers

Name:______________________________

Period or small group:____________

Please answer the following questions by circling the correct answer. To get full credit for question four you must show your work. These problems are easily solved by predicting the factors. Example:

Problem:

The time to take a trip by car is inversely related to the speed of the car. The faster the car travels the less time it takes to complete the trip. Suppose that a trip takes 3 hours at 45 m.p.h. How long would the trip take at 55 m.p.h.?

$$3 \text{ hours} \times \frac{45\ \text{m.}\cancel{\text{p}}\text{.h.}}{55\ \text{m.}\cancel{\text{p}}\text{.h.}} = 2.45 \text{ hours}$$

1. A sample of gas has a volume of1500 ml at 900 mm Hg pressure. What volume would this gas occupy at 1200 mm Hg?

   A. 720 ml B. 1125 ml

   C. 3600 ml D. 6000 ml

2. What would be the volume of a sample of gas at 800 mm Hg pressure, if at 300 mm Hg pressure the volume was 600 ml?

   A. 225 ml B. 400 ml

   C. 1600 ml D. 1833 ml

3. A sample of gas has a pressure of 632 mm Hg and a volume of 492 ml. What would be the pressure of this sample of gas, if the volume became 856 ml?

   A. 363 mm Hg B. 666 mm Hg

   C. 996 mm Hg D. 1100 mm Hg

4. What would be the pressure of a sample of gas of 1000 ml volume, if at 1400 ml volume the pressure was 500 mm Hg? (Show your work).

   A. 357 mm Hg B. 480 mm Hg

   C. 700 mm Hg D. 2800 mm Hg

Name ______________________________ Period or Small Group _________ Gas Laws II-QF-1

Please answer the following questions by circling the correct answer. To get full credit for question four, you must show your work. Remember to set up your factors based upon your prediction of what should happen. The relationship between the temperature and volume is a direct one. Another direct relationship is the one between the cost of objects and the number you buy. Example: If chewing gum is 73¢ for 3 packages, how much will 9 packages cost?

$$73¢ \times \frac{9 \text{ packages}}{3 \text{ packages}} = 219¢ \text{ or } \$2.19$$

1. A sample of gas has a volume of 625 ml at 27°C. What would be the volume at 55°C?

   A. 307 ml B. 572 ml

   C. 683 ml D. 1273 ml

2. What would be the Celsius temperature of a sample of gas of 350 ml volume, if at 400 ml volume, the temperature was 46°C?

   A. 6°C B. 40°C

   C. 53°C D. 237°C

3. What would be the volume of a sample of gas at 63.4°C, if at 121.2°c, its volume was 457 ml?

   A. 238.5 ml B. 389.9 ml

   C. 534.3 ml D. 871.7 ml

4. A sample of gas has a volume of 275 ml at -10°C. What would be the temperature at 520 ml volume?

   A. -272°C B. -254°C

   C. -134°C D. 224°C

Name: ______________________________

Period or small group: ____________

Please answer the following questions by circling the correct answer. To get full credit for question four you must show your work. Remember to set up your factors based upon your prediction of what should happen. The relationship between the volume or pressure and temperature is a direct relationship, while the relationship between pressure and volume is an inverse relationship.

An example of a problem using both a direct and an inverse relationship might be: How much would a truck driver be paid if he got $10.00 per hour for a trip of 275 miles if he averaged 55 miles per hour?

$$\overset{5}{275}\ \text{miles} \times \frac{1\ \text{hour}}{\underset{1}{55}\ \text{miles}} \times \frac{10\ \text{dollars}}{1\ \text{hour}} = 50\ \text{dollars}$$

1. A sample of gas has a volume of 400 ml at 600 mm Hg and -73°C. What would be the volume at 1500 mm Hg and 27°C?

   A. 107 ml
   B. 240 ml
   C. 433 ml
   D. 1500 ml

2. A sample of gas has a pressure of 600 mm Hg at 0°C and 900 ml. What would be the pressure at 273°C and 300 ml?

   A. 100 mm Hg
   B. 400 mm Hg
   C. 900 mm Hg
   D. 3600 mm Hg

3. What would be the Celsius temperature of a sample of gas at 500 mm Hg and 500 ml, if at 57°C the pressure was 1000 mm Hg and 1500 ml volume?

   A. -218°C
   B. -53°C
   C. 55°C
   D. 222°C

4. A sample of gas has a volume of 632.4 ml at 25.3°C and 784.6 mm Hg. What would be the volume at 51.6°C and 954.2 mm Hg?

   A. 477.9 ml
   B. 565.8 ml
   C. 753.8 ml
   D. 1060.5 ml

Item Analysis for Gas Laws

Immediate and Delayed Posttest

Measure-Item		Response Percentage				
		A	B	C	D	Blank
Quiz 1	1	1.3	94.34*	.7	.2	.4
Quiz 1	2	80.3*	1.8	14.0	.5	.2
Quiz 1	3	92.1*	1.5	.2	2.7	.4
Quiz 1	4	12.0	.4	82.8*	1.3	.4
Quiz 2	1	.5	5.5	88.0*	3.1	0
Quiz 2	2	83.6*	8.0	3.3	2.0	.2
Quiz 2	3	4.7	79.6*	8.9	.4	2.5
Quiz 2	4	2.2	2.9	6.6	84.7*	.5
Quiz 3	1	4.2	83.0*	1.6	7.3	.2
Quiz 3	2	2.7	9.1	10.0	74.1*	.4
Quiz 3	3	69.3*	6.4	10.8	9.5	.4
Quiz 3	4	7.8	77.2*	5.7	4.0	1.6
Test	1	21.2	69.0*	3.3	2.9	0
Test	2	7.1	73.4*	12.8	2.9	0
Test	3	77.2*	4.0	6.2	8.8	.2
Test	4	8.2	10.2	11.1	66.4*	.4
Test	5	67.7*	25.2	2.0	1.3	.2
Test	6	28.5	62.0*	2.0	3.3	.5
Test	7	70.4*	3.8	13.9	7.5	.5
Test	8	12.4	7.1	73.4*	2.7	.4
Test	9	5.7	12.2	74.6*	3.6	.2
Test	10	8.6	25.0	45.1*	14.6	2.9

* Correct answer

Name: ______________________________ Gas Laws-T-1

Period or small group: ____________

Please answer the following questions by circling the correct answer.

1. A gas sample has a volume of 200 ml at 800 mm Hg. What would be the volume at 400 mm Hg if there is no temperature change?

   A. 100 ml
   B. 400 ml
   C. 1600 ml
   D. 6400 ml

2. A gas sample has a volume of 300 ml at 52°C. What would be the Celsius temperature of this sample if the volume was increased to 900 ml? Assume no pressure change.

   A. -165°C
   B. 702°C
   C. 975°C
   D. 1148°C

3. A gas sample has a pressure of 500 mm Hg at -73°C. Assuming that the volume stays constant, what would be the Celsius temperature of this sample at 250 mm Hg?

   A. -173°C
   B. -146°C
   C. -36.5°C
   D. 100°C

4. A gas sample has a volume of 900 ml at 0°C and 250 mm Hg. If the volume becomes 300 ml and the temperature 273°C, what would be the pressure?

   A. 42 mm Hg
   B. 167 mm Hg
   C. 375 mm Hg
   D. 1500 mm Hg

5. A gas sample has a volume of 326.5 ml at 635.2 mm Hg. Assuming no temperature change, what would be the volume at 947.6 mm Hg?

   A. 218.9 ml
   B. 487.1 ml
   C. 1843.5 ml
   D. 1909.3 ml

6. The pressure of a gas is directly related to the number of molecules of the gas. If a gas sample contained 12×10^{23} molecules at a pressure of 1500 mm Hg, what would be the pressure if the number of molecules was increased to 18×10^{23} molecules? Assume no volume or temperature change.

   A. 1000 mm Hg
   B. 2250 mm Hg
   C. 0.001×10^{23} mm Hg
   D. 2.25×10^{23} mm Hg

7. A gas sample has a volume of 500 ml at 800 mm Hg and -23°C. What would be the Celsius temperature if the pressure was changed to 1000 mm Hg and the volume to 200 ml?

   A. -148°C
   B. 11.5°C
   C. 125°C
   D. 781°C

8. What would be the volume of a gas sample at 150 mm Hg and 177°C, if at 700 mm Hg and 77°C the volume was 750 ml?

   A. 207 ml
   B. 250 ml
   C. 4500 ml
   D. 8045 ml

9. A gas sample has a volume of 660 ml at 27°C. What would be the volume of this sample at 127°C?

   A. 140 ml
   B. 495 ml
   C. 880 ml
   D. 3104 ml

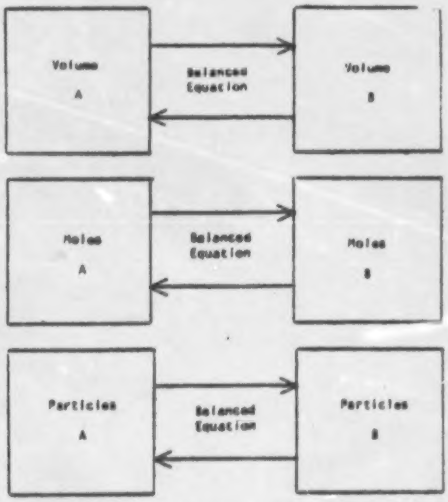
10. What volume would five moles of a gas occupy at 27°C and 760 mm Hg? (760 mm Hg = 1 atmosphere).

    A. 22.4 liters
    B. 102 liters
    C. 123 liters
    D. 284 liters

Name: ______________________________

Period or small group: ____________

Please answer the following questions by circling the correct answer. To get full credit for question 4 you must show your work. The relationships for particles, moles, and volume may be summarized by:



1. When the compound potassium chlorate ($KClO_3$) is heated it breaks down into potassium chloride (KCl) and oxygen gas (O_2). This is represented by the equation $2\ KClO_{3(s)} \longrightarrow 2\ KCl_{(s)} + 3O_{2\ (g)}$, How many moles of O_2 would be formed from 6 moles of $KClO_3$?

   A. 4 moles B. 6 moles

   C. 9 moles D. 12 moles

2. Carbon monoxide gas will burn (react with O_2) to form carbon dioxide gas according to the reaction $2\ CO_{(g)} + O_{2\ (g)} \longrightarrow 2\ CO_{2\ (g)}$. How many liters of CO_2 would be formed at STP from 18 liters of oxygen and excess carbon monoxide?

   A. 9 liters B. 18 liters

   C. 22.4 liters D. 36 liters

3. Propane gas (C_3H_8) will react with oxygen gas (O_2) to form carbon dioxide(CO_2)gas and water vapor (H_2O). This is represented by the equation $C_3H_8 + 5\ O_2 \longrightarrow 3\ CO_2 + 4\ H_2O$. How many molecules of oxygen will be needed to react completely with 5×10^{23} molecules of propane?

   A. 5 molecules B. 25 molecules

   C. 1×10^{23} molecules D. 25×10^{23} molecules

4. How many liters of CO_2 gas would be produced at STP if 24.3 liters of C_3H_8 reacted with excess oxygen according to the reaction $C_3H_{8\ (g)} + 5\ O_{2\ (g)} \longrightarrow 3\ CO_{2\ (g)} + 4\ H_2O_{\ (g)}$?

   A. 3.0 liters B. 8.1 liters

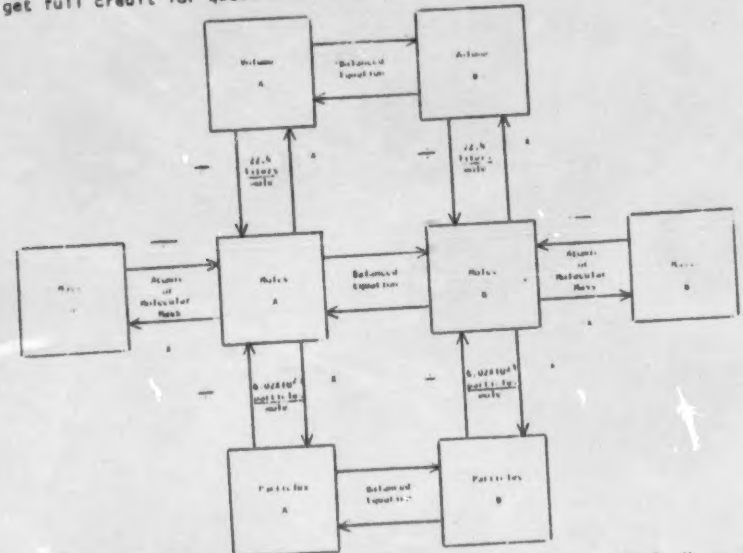
   C. 22.4 liters D. 72.9 liters

Name: ______________________

Period or small group: __________

Please answer the following questions by circling the correct answer.

To get full credit for question four you must show your work.


Volume A
Balanced Equation
Volume B
22.4 liters/mole
22.4 liters/mole
Mass A
Atomic or Molecular Mass
Moles A
Balanced Equation
Moles B
Atomic or Molecular Mass
Mass B
6.02x10²³ particles/mole
6.02x10²³ particles/mole
Particles A
Balanced Equation
Particles B

Atomic Masses you may need: P = 31.0, O = 16.0, Na = 23.0, H = 1.0,
N = 14.0, S = 32.1

1. White phosphorus (P_4) reacts with oxygen gas (O_2) to form P_4O_6 (s). The balanced reaction is $P_4 (s) + 3 O_2 (g) \longrightarrow P_4O_6 (s)$. How many grams of P_4O_6 would be produced if 96.0 grams of O_2 react with excess P_4?

   A. 47.0 grams B. 106.7 grams

   C. 220.0 grams D. 960.0 grams

2. Sodium metal (Na) reacts with water (H_2O) to form sodium hydroxide (NaOH) and hydrogen gas (H_2). The balanced equation is: $2 Na (s) + 2 H_2O (\ell) \longrightarrow 2 NaOH (aq) + H_2 (g)$. How many grams of sodium would be needed to produce 67.2 liters of H_2 (measured at STP) if the sodium reacts with excess water?

   A. 34.5 grams B. 134.3 grams

   C. 138.0 grams D. 276.0 grams

3. Sodium nitrate ($NaNO_3$) can be decomposed into sodium nitrite ($NaNO_2$) and oxygen gas (O_2). The balanced equation is $2 NaNO_3 (s) \longrightarrow 2 NaNO_2 (s) + O_2 (g)$. How many molecules of oxygen gas can be produced from 85.0 grams of $NaNO_3$?

   A. 3.01×10^{23} molecules B. 6.02×10^{23} molecules

   C. 12.04×10^{23} molecules D. 256×10^{23} molecules

4. Sulfur (S_8) reacts with oxygen gas (O_2) to form sulfur dioxide (SO_2). The balanced equation is $S_8 (s) + 8 O_2 (g) \longrightarrow 8 SO_2 (g)$. How many grams of SO_2 would be formed when 72.5 grams of S_8 reacts with excess oxygen.

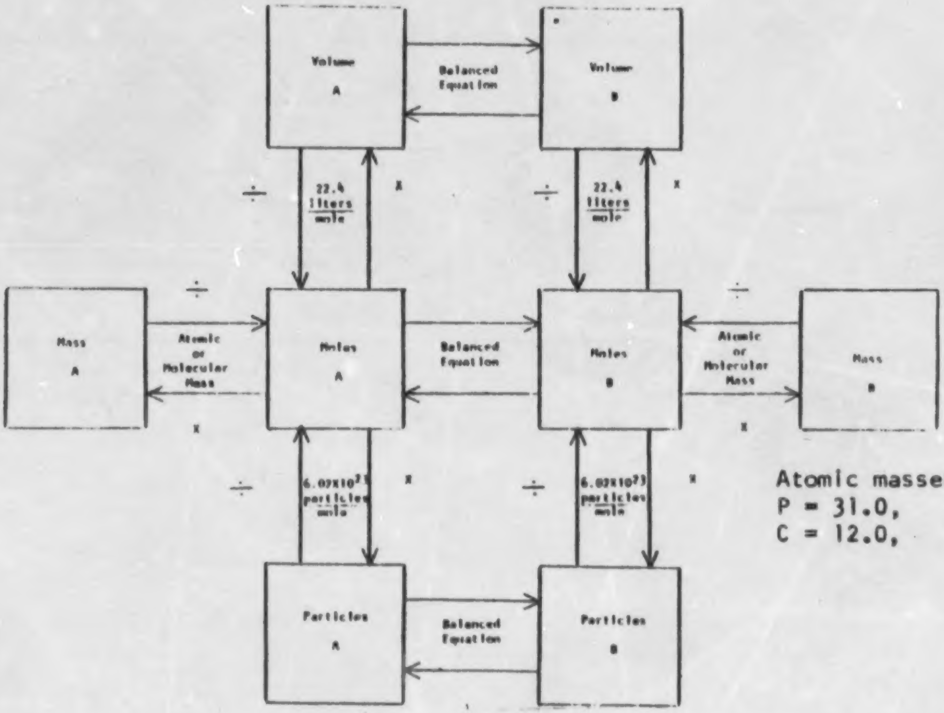
   A. 18.1 grams B. 144.8 grams

   C. 580.0 grams D. 1158.2 grams

Name ____________________________

Period or Small Group ____________

Please answer the following questions by circling the correct answer. To get full credit for question four you must show your work.


Volume A
Balanced Equation
Volume B
÷
22.4 liters/mole
x
÷
22.4 liters/mole
x
Mass A
÷
Atomic or Molecular Mass
x
Moles A
Balanced Equation
Moles B
÷
Atomic or Molecular Mass
x
Mass B
÷
6.02x10²³ particles/mole
x
÷
6.02x10²³ particles/mole
x
Particles A
Balanced Equation
Particles B

Atomic masses you may need:
P = 31.0, Cl = 35.5
C = 12.0, H = 1.0

1. White phosphorous (P_4) reacts with chlorine gas (Cl_2) to form $PCl_{3(s)}$. The balanced equation is $P_{4(s)} + 6Cl_{2(g)} \longrightarrow 4PCl_{3(s)}$. How many molecules of PCl_3 would be formed from 67.2 liters of Cl_2 (measured at STP) and excess P_4?

   A. 1.00×10^{23} molecules B. 4.01×10^{23} molecules
   C. 12.04×10^{23} molecules D. 27.09×10^{23} molecules

Use the following reaction for questions 2, 3, and 4.

$$C_3H_{8(g)} + 5O_{2(g)} \longrightarrow 3CO_{2(g)} + 4H_2O_{(g)}$$

2. If the gases are measured at STP, how many liters of carbon dioxide (CO_2) would be formed from 20 liters of O_2 and excess C_3H_8?

   A. 2.7 liters B. 12.0 liters
   C. 33.3 liters D. 100 liters

3. How many grams of water would be formed from 112 liters of C_3H_8 (measured at STP) and excess O_2?

   A. 22.5 grams B. 90.0 grams
   C. 360.0 grams D. 448.0 grams

4. How many molecules of carbon dioxide would be formed if 84.5 liters of C_3H_8 (measured at STP) reacted with excess O_2?

   A. 0.53×10^{23} molecules B. 4.8×10^{23} molecules
   C. 7.6×10^{23} molecules D. 68.1×10^{23} molecules

Name: ______________________ S-T-1

Period or small group: __________

Please answer the following questions by circling the correct answer.

You may need the following atomic masses and constants:

C = 12.0 H = 1.0 N = 14.0 O = 16.0

Fe = 55.9 1 mole = 22.4 liters at STP = 6.02×10^{23} particles

The following balanced equation may be used for questions one through six.

$$4\ NH_3\ (g) + 5\ O_2\ (g) \longrightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$$

1. How many moles of nitrous oxide (NO) will be produced when 10.0 moles of oxygen gas (O_2) reacts with sufficient ammonia gas (NH_3)?

A. 4.0 moles
B. 8.0 moles
C. 10.0 moles
D. 12.5 moles

2. How many grams of water (H_2O) will be produced when 34.0 grams of ammonia (NH_3) reacts with sufficient oxygen gas (O_2)?

A. 3.0 grams
B. 24.0 grams
C. 51.0 grams
D. 54.0 grams

3. How many molecules of oxygen gas (O_2) are necessary to react completely with 56.0 liters of ammonia (NH_3) measured at STP?

A. 3.01×10^{23} molecules
B. 12.04×10^{23} molecules
C. 15.05×10^{23} molecules
D. 18.81×10^{23} molecules

4. How many grams of water (H_2O) will be produced when 18.06×10^{23} molecules of nitrous oxide (NO) are produced?

A. 36.0 grams
B. 54.0 grams
C. 81.0 grams
D. 325.1 grams

5. How many liters of water (H_2O) will be formed when 44.8 liters of ammonia (NH_3) are mixed with 134.3 liters of O_2 at STP?

A. 29.9 liters
B. 67.2 liters
C. 80.6 liters
D. 537.6 liters

6. How many liters of nitrous oxide (NO) will be produced when 67.2 liters of oxygen gas (O_2) react with sufficient ammonia (NH_3)?

A. 3.75 liters
B. 53.8 liters
C. 84.0 liters
D. 104.4 liters

Use the following balanced reactions for questions seven through ten.

$$Fe_2O_3\ (s) + 3\ CO_{(g)} \longrightarrow 2\ Fe\ (s) + 3\ CO_2\ (g)$$

7. How many grams of iron (Fe) will be produced from 3.0 moles of iron (III) oxide (Fe_2O_3)reacting with sufficient CO?

A. 6.0 grams
B. 9.32 grams
C. 83.9 grms
D. 335.4 grams

8. How many grams of iron (Fe) will be produced when 78.4 liters of carbon monoxide (CO), measured at STP, reacts with sufficient Fe_2O_3?

A. 111.8 grams
B. 130.4 grams
C. 195.7 grams
D. 293.5 grams

9. Some of one of the reactants (CO or Fe_2O_3) will be left over after 319.6 grams of iron (III) oxide (Fe_2O_3) are mixed with 196.0 grams of CO. Which reactant is it and how much will be left?

A. 28.0 grams CO
B. 113.6 grams Fe_2O_3
C. 168.0 grams CO
D. 372.9 Fe_2O_3

10. How many atoms of Fe would be produced when 12.04×10^{23} molecules of CO react with sufficient Fe_2O_3?

A. 8.03×10^{23} atoms
B. 16.06×10^{23} atoms
C. 18.06×10^{23} atoms
D. 24.08×10^{23} atoms

Item Analysis for Stoichiometry

Immediate and Delayed Posttest

Measure-Item		Response Percentage A	B	C	D	Blank
Quiz 1	1	6.0	4.0	86.9*	2.7	0
Quiz 1	2	5.5	10.6	.4	83.2*	0
Quiz 1	3	2.0	4.4	5.5	87.8*	0
Quiz 1	4	2.2	5.7	3.3	86.3*	2.2
Quiz 2	1	3.5	5.7	84.9*	3.5	.7
Quiz 2	2	8.4	12.8	68.4*	8.0	.6
Quiz 2	3	60.8*	14.4	17.2	4.9	.9
Quiz 2	4	10.6	60.8*	13.3	9.9	3.7
Quiz 3	1	1.8	4.2	88.7*	4.2	.2
Quiz 3	2	6.4	78.8*	8.0	5.1	.7
Quiz 3	3	6.4	6.8	73.7*	12.0	.2
Quiz 3	4	2.6	6.6	8.6	79.2*	2.2
Test	1	8.4	82.9*	2.9	4.4	.2
Test	2	8.2	8.0	22.1	59.3*	1.1
Test	3	4.6	11.9	13.1	68.6*	.6
Test	4	7.1	12.2	70.3*	8.4	.7
Test	5	7.3	75.7*	7.9	4.9	2.9
Test	6	5.3	78.1*	11.1	2.7	1.3
Test	7	9.1	5.3	17.0	65.9*	1.3
Test	8	9.7	65.2*	11.5	11.0	1.3
Test	9	36.1*	27.9	18.6	11.3	4.6
Test	10	64.4*	13.3	7.5	10.9	2.4

* Correct answer

Name:______________________________ Mo-1-QP-1

Period or small group:__________________

Please answer the following questions by circling the correct answer. In order to get full credit for question five, you must show your work. Remember to use proportions when you can to work the problems.

Example: How many gallons of gas could a person purchase for \$5.00 if the gas is \$1.10 per gallon?

$$\frac{x}{\$5.00} = \frac{1\text{ gallon}}{\$1.10} \qquad (x)(\$1.10) = (\$5.00)(1\text{ gallon})$$

$$x = \frac{(\$5.00)(1\text{ gallon})}{(\$1.10)} = 4.55\text{ gallons}$$

All of the following questions deal with the substance potassium chloride (KCl) which has a molecular mass of 74.6 grams per mole.

1. What would be the molarity of a solution made by dissolving 6.0 moles of potassium chloride (KCl) in enough water to make 3.0 liters of solution?

   A. 0.5 M B. 2.0 M

   C. 3.0 M D. 6.0 M

2. What would be the molarity of a solution made by dissolving 149.2 grams of KCl in enough water to make 1200 ml of solution?

   A. 0.42 M B. 0.60 M

   C. 1.67 M D. 2.40 M

3. How many grams of KCl would be present in 1600 ml of a 0.50 M KCl solution?

   A. 23.3 grams B. 59.7 grams

   C. 93.3 grams D. 238.7 grams

4. What would be the molarity of a solution made by dissolving 0.45 moles of KCl in enough water to make 1400 ml of solution?

   A. 0.32 M B. 3.1 M

   C. 28.0 M D. 35.7 M

5. How many milliters of a 1.6 M KCl solution would contain 14.9 grams of KCl?

   A. 8.0 ml B. 125 ml

   C. 320 ml D. 3125 ml

Name:____

Period or small group:________________________

Please answer the following questions by circling the correct answer. To get full credit for question five, you must show your work. Remember to set up proportions whenever possible to help solve the problems.

Example: A jet can travel 500 miles per hour. How many hours would a trip of 2500 miles take?

$$\frac{x}{2500 \text{ miles}} = \frac{1 \text{ hour}}{500 \text{ miles}} \qquad (x)(500 \text{ miles}) = (2500 \text{ miles})(1 \text{ hour})$$

$$x = \frac{(2500 \cancel{\text{miles}})(1 \text{ hour})}{(500 \cancel{\text{miles}})} = 5 \text{ hours}$$

1. What would be the molarity of a solution made by boiling off 500 ml of water from 2500 ml of a 2.0 M NaCl solution?

A. 0.40 M
B. 0.625 M
C. 1.67 M
D. 2.50 M

2. What would be the molarity of a solution made by adding 1.0 liter of water to 2.0 liters of a 3.0 M NaCl solution?

A. 0.22 M
B. 0.50 M
C. 2.0 M
D. 6.0 M

3. How many milliliters of water must be added to 750 ml of a 1.25 M NaCl solution to reduce the molarity to 0.50 M?

A. 217 ml
B. 1125 ml
C. 2583 ml
D. 2625 ml

4. What would be the molarity of a solution made by adding 850 ml of water to 1400 ml of a 2.6 M NaCl solution?

A. 0.62 M
B. 0.83 M
C. 1.62 M
D. 6.62 M

5. How many milliliters of water must be boiled away from 1200 ml of 1.6 M NaCl to produce a 2.0 M NaCl solution?

A. 160 ml
B. 240 ml
C. 533 ml
D. 2160 ml

Name:____

Period or small group:__________________________

Please answer the following questions by circling the correct answer. To get full credit for question five, you must show your work. Remember to set up proportions when working the problems. Example:

A trucker can by diesel fuel for $1.10 per gallon. How much money would it take for a trucker to fill up a 50 gallon tank?

$$\frac{x}{50 \text{ gallons}} = \frac{\$1.10}{1 \text{ gallon}} \qquad (x)(1 \text{ gallon}) = (50 \text{ gallons})(\$1.10)$$

$$x = \frac{(50 \text{ gallons})(\$1.10)}{(1 \text{ gallon})} = \$55.00$$

Questions one through four deal with the following balanced reaction:

$$2\ HCl_{(aq)} + Mg(OH)_{2(aq)} \longrightarrow MgCl_{2(aq)} + 2\ H_2O_{(l)}$$

Molecular Masses: $HCl = 36.5$; $Mg(OH)_2 = 58.3$; $MgCl_2 = 95.3$; $H_2O = 18.0$

1. How many moles of magnesium chloride ($MgCl_2$) would be produced when 2.0 liters of 1.0 M hydrochloric acid (HCl) reacts with a sufficient amount of magnesium hydroxide $Mg(OH)_2$?

A. 0.5 mole
B. 1.0 mole
C. 2.0 moles
D. 4.0 moles

2. How many grams of magnesium hydroxide ($Mg(OH)_2$) are needed to react completely with 500 ml of a 1.20 M hydrochloric acid (HCl) solution?

A. 17.5 grams
B. 70.0 grams
C. 194.3 grams
D. 279.8 grams

3. What would be the molarity of 1500ml of magnesium chloride ($MgCl_2$) solution formed when 1200 ml of a 4.0 M hydrochloric acid solution reacts with sufficient magnesium hydroxide ($Mg(OH)_2$)?

A. 0.10 M
B. 1.6 M
C. 3.2 M
D. 6.4 M

4. How many moles of magnesium chloride ($MgCl_2$) would be produced when 1800 ml of 0.36 M hydrochloric acid (HCl) reacts with a sufficient amount of magnesium hydroxide $Mg(OH)_2$?

A. 0.32 mole
B. 0.65 mole
C. 1.30 moles
D. 2.50 moles

5. Sodium carbonate (Na_2CO_3) will react with hydrochloric acid (HCl) to form sodium chloride (NaCl), water (H_2O) and carbon dioxide (CO_2). How many liters of CO_2 (measured at STP) will be produced when 300 ml of 6.0 M HCl reacts with sufficient Na_2CO_3? Reaction: $Na_2CO_{3\,(s)} + 2\ HCl_{(aq)} \longrightarrow 2\ NaCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$

A. 2.24 liters
B. 20.2 liters
C. 74.7 liters
D. [illegible] liters

Name: ______________________________ Mo-T-1

Period or Small Group: ____________________

Please answer the following questions by circling the correct answer.

You __may__ need the following molecular masses and constants.

$NaCl$ = 58.5 CH_3OH = 32.0 Li_2CO_3 = 73.8 HNO_3 = 63.0

$LiNO_3$ = 68.9 CO_2 = 44.0 H_2O = 18.0

1 mole = 22.4 liters at STP 1 mole = 6.02×10^{23} particles

1. What would be the molarity of a solution made by dissolving 2.5 moles of NaCl in enough water to form 1.5 liters of solution?

   A. 0.60 M B. 1.67 M

   C. 3.75 M D. 6.00 M

2. What volume of a 2.0 M Li_2NO_3 solution would contain 37.9 grams of Li_2NO_3?

   A. 275 ml B. 910 ml

   C. 1306 ml D. 3640 ml

3. What volume of water must be added to 500 ml of 1.75 M NaCl solution to reduce the molarity to 1.25M?

   A. 200 ml B. 594 ml

   C. 700 ml D. 2300 ml

4. What would be the molarity of 2.0 liters of a 4.0 M NaCl solution after 800 ml of the solution is boiled off?

   A. 0.15 M B. 1.67 M

   C. 6.67 M D. 10.0 M

5. How many molecules of methyl alcohol CH_3OH would be in 1500 ml of a 2.0 M CH_3OH solution?

   A. 2.01×10^{23} molecules B. 4.52×10^{23} molecules

   C. 8.03×10^{23} molecules D. 18.06×10^{23} molecules

Problems six through ten deal with the following __balanced__ equation:

$$Li_2CO_{3(s)} + 2HNO_{3(aq)} \longrightarrow 2LiNO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$$

6. How many grams of CO_2 would be formed from 2.0 liters of a 1.4 M HNO_3 solution reacting with sufficient Li_2CO_3?

   A. 31.4 grams B. 61.6 grams

   C. 125.8 grams D. 246.4 grams

7. What would be the molarity of the $LiNO_3$ solution formed when 73.8 grams of Li_2CO_3 and 750 ml of 4.0 M HNO_3 are mixed?

   A. 0.67 M B. 2.67 M

   C. 5.33 M D. 7.11 M

8. How many moles of H_2O would be formed when 1.5 liters of 3.0 M HNO_3 reacts with sufficient Li_2CO_3?

   A. 8.0 grams B. 18.0 grams

   C. 40.5 grams D. 162.0 grams

9. How many liters of CO_2, measured at STP, would be formed from 200 ml of a 8.0 M HNO_3 solution reacting with sufficient Li_2CO_3?

   A. 17.9 liters B. 28.0 liters

   C. 71.7 liters D. 448.0 liters

10. What would be the molarity of the HNO_3 that reacted with sufficient Li_2CO_3 to produce 54.0 grams of H_2O if the solution had a volume of 1.5 liters?

    A. 0.25 M B. 0.44 M

    C. 1.00 M D. 4.00 M

Item Analysis for Molarity

Immediate and Delayed Posttest

	Response Percentage				
Measure-Item	A	B	C	D	Blank
Quiz 1 1	.7	94.7*	.6	.7	0
Quiz 1 2	4.2	3.8	76.1*	12.2	.4
Quiz 1 3	17.5	65.2*	4.0	9.3	.9
Quiz 1 4	83.2*	6.6	4.0	2.4	.6
Quiz 1 5	14.8	51.6*	20.3	8.4	1.6
Quiz 2 1	9.3	6.4	3.8	73.5*	.4
Quiz 2 2	1.5	4.4	59.7*	27.9	0
Quiz 2 3	7.3	69.9*	4.7	10.0	1.6
Quiz 2 4	6.0	6.8	68.4*	11.1	1.1
Quiz 2 5	8.8	73.2*	4.9	4.2	2.4
Quiz 3 1	2.9	65.7*	12.4	2.9	0
Quiz 3 2	69.0*	8.4	4.0	2.2	.4
Quiz 3 3	3.7	54.0*	20.3	5.7	.4
Quiz 3 4	61.7*	14.1	5.8	2.2	.2
Quiz 3 5	5.7	71.9*	2.9	2.2	1.3
Test 1	2.7	60.8*	16.8	3.5	.2
Test 2	50.6*	11.0	12.4	9.1	.9
Test 3	37.8*	5.7	36.5	3.5	.6
Test 4	3.5	11.1	36.7*	31.9	.7
Test 5	2.4	7.7	5.3	68.1*	.7
Test 6	4.6	65.7*	5.3	7.9	.7
Test 7	17.5	36.3*	20.4	7.7	2.2
Test 8	6.6	5.9	64.2*	3.1	.7
Test 9	61.0*	11.5	7.9	3.1	.7
Test 10	7.7	12.2	8.4	53.1*	2.4

* Correct answer

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                                             ITEM ANALYSIS

                                                Regular

ITEM          T                 F                                                                 PERCENT CORRECT                DOUBLY
 NO.          A                 B                 C                 D                 E       UPPER THIRD   LOWER THIRD   BLANK   MARKED


  1       R=   .40 *G      R=  -.25       R=  -.13       R=  -.16       R=   .00         88            44            5        0
          D= 68.61         D= 11.44       D=  9.49       D=  9.25       D=   .00

  2       R=  -.09         R=  -.19       R=  -.16       R=   .24 *     R=  -.03         89            70            1        0
          D=  3.16         D=  7.30       D=  7.54       D= 81.27       D=   .49

  3       R=  -.13         R=  -.26       R=  -.31       R=   .50 *G    R=  -.03         93            40            5        0
          D=  3.41         D=  7.06       D= 18.25       D= 69.83       D=   .24

  4       R=  -.03         R=   .25 *G    R=  -.11       R=  -.21       R=   .00         67            44            4        1
          D= 19.22         D= 53.53       D= 17.52       D=  8.52       D=   .00

  5       R=   .44 *G      R=  -.19       R=  -.24       R=  -.18       R=  -.06         88            41            5        0
          D= 65.45         D=  9.00       D= 16.30       D=  7.79       D=   .24

  6       R=  -.15         R=   .25 *     R=  -.06       R=  -.10       R=  -.05         65            38            3        0
          D=  7.30         D= 50.61       D= 15.82       D= 25.30       D=   .24

  7       R=  -.20         R=  -.11       R=   .30 *G    R=  -.06       R=   .00         66            34            3        0
          D= 20.44         D=  5.60       D= 47.69       D= 25.55       D=   .00

  8       R=   .37 *G      R=  -.05       R=  -.26       R=  -.06       R=  -.00         55            18            8        0
          D= 35.04         D= 22.14       D= 23.36       D= 17.27       D=   .24

  9       R=  -.03         R=  -.07       R=  -.27       R=   .32 *G    R=   .04         73            40            3        0
          D=  7.06         D=  6.08       D= 28.22       D= 57.42       D=   .49

 10       R=  -.17         R=  -.10       R=   .39 *G    R=  -.23       R=  -.05         76            33            6        0
          D= 13.14         D= 21.90       D= 52.31       D= 10.95       D=   .24

 11       R=  -.09         R=  -.13       R=  -.11       R=   .35 *     R=   .10         45            14            3        0
          D= 30.17         D= 27.49       D= 13.93       D= 27.98       D=   .00

 12       R=   .43 *       R=  -.09       R=  -.21       R=  -.15       R=   .00         57            18           23        0
          D= 34.79         D= 36.98       D= 15.57       D=  7.06       D=   .00

 13       R=  -.20         R=   .46 *G    R=  -.26       R=  -.18       R=   .09         91            39            7        0
          D= 10.46         D= 64.96       D= 15.57       D=  7.06       D=   .24

 14       R=  -.23         R=  -.14       R=  -.17       R=   .45 *G    R=  -.00         70            20            6        0
          D= 16.55         D= 24.09       D= 14.36       D= 43.31       D=   .24

 15       R=  -.14         R=  -.09       R=   .34 *G    R=  -.22       R=   .00         65            28            5        0
          D=  8.76         D= 27.49       D= 47.20       D= 15.33       D=   .00

 16       R=  -.04         R=  -.03       R=   .16 *     R=  -.04       R=  -.05         38            25            6        0
          D= 21.17         D= 30.90       D= 29.20       D= 17.03       D=   .24

 17       R=  -.19         R=  -.10       R=   .38 *G    R=  -.12       R=   .00         85            53           13        0
          D=  9.73         D=  9.73       D= 71.29       D=  6.08       D=   .00
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ITEM ANALYSIS

Regular

ITEM	T	F				PERCENT CORRECT		BLANK	DOUBLY
NO.	A	B	C	D	E	UPPER THIRD	LOWER THIRD		MARKED
18	R= -.15 D= 5.60	R= -.27 D= 29.44	R= -.07 D= 10.95	R= .39 *G D= 52.55	R= .00 D= .00	75	32	6	0
19	R= -.14 D= 12.90	R= -.16 D= 20.44	R= .36 *G D= 56.69	R= -.14 D= 8.70	R= -.05 D= .24	77	37	4	0
20	R= -.02 D= 28.71	R= .28 *G D= 48.91	R= -.17 D= 13.63	R= -.22 D= 6.08	R= -.05 D= .24	64	33	10	0
21	R= -.05 D= 13.38	R= -.07 D= 10.22	R= -.06 D= 41.61	R= .19 * D= 33.09	R= .00 D= .00	43	26	7	0
22	R= .30 *G D= 49.88	R= -.18 D= 23.60	R= .02 D= 12.90	R= -.16 D= 11.44	R= -.05 D= .73	67	33	6	0
23	R= -.03 D= 15.82	R= .18 * D= 37.96	R= -.02 D= 25.79	R= -.10 D= 17.52	R= -.04 D= .24	49	33	11	0
24	R= .27 * D= 32.12	R= -.18 D= 26.76	R= -.10 D= 11.19	R= .03 D= 26.03	R= .00 D= .00	44	22	16	0
25	R= .24 * D= 38.69	R= -.12 D= 15.82	R= -.10 D= 23.11	R= -.01 D= 20.19	R= .00 D= .00	51	28	9	0
26	R= -.22 D= 9.25	R= -.21 D= 12.90	R= .39 *G D= 59.12	R= -.06 D= 14.36	R= -.05 D= .24	78	36	17	0
27	R= -.04 D= 24.82	R= .22 * D= 33.58	R= -.04 D= 21.17	R= -.08 D= 15.82	R= -.07 D= .49	43	25	17	0
28	R= .14 * D= 21.41	R= .12 D= 38.69	R= -.12 D= 26.28	R= -.07 D= 8.03	R= -.06 D= .24	30	16	22	0
29	R= .36 * D= 29.93	R= -.12 D= 14.84	R= -.07 D= 32.60	R= -.13 D= 16.06	R= .00 D= .00	51	15	27	0
30	R= -.08 D= 11.44	R= -.10 D= 12.17	R= .20 * D= 53.04	R= .04 D= 18.00	R= -.07 D= .49	65	44	20	0
31	R= -.01 D= 13.87	R= -.14 D= 25.06	R= -.10 D= 29.93	R= .35 * D= 25.55	R= .00 D= .00	46	16	23	0
32	R= -.21 D= 8.03	R= .44 *G D= 64.72	R= -.20 D= 11.68	R= -.14 D= 10.71	R= .00 D= .00	88	42	20	0
33	R= -.07 D= 22.38	R= .25 * D= 28.71	R= -.06 D= 28.95	R= -.04 D= 11.19	R= -.05 D= .24	42	19	35	0
34	R= -.10 D= 8.52	R= .02 D= 14.60	R= .01 D= 35.04	R= .17 * D= 31.63	R= -.06 D= .73	40	27	39	0

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                                                     ITEM ANALYSIS
                                                        Regular

 ITEM            T               F                                                             PERCENT CORRECT                    DOUBLY
  NO.            A               B               C              D              E         UPPER THIRD   LOWER THIRD     BLANK     MARKED

  35         R=   .33 *      R=  -.11        R=  -.03       R=  -.12       R=  -.07           45            16            28          0
             D= 26.52        D=  7.54        D= 41.12       D= 17.52       D=   .49

  36         R=  -.17        R=   .39 *G     R=  -.13       R=  -.05       R=   .00           61            24            32          0
             D= 20.19        D= 38.93        D= 12.17       D= 20.92       D=   .00

  37         R=   .21 *      R=   .01        R=  -.08       R=   .02       R=   .00           34            16            33          0
             D= 22.63        D= 14.84        D= 28.22       D= 26.28       D=   .00

  38         R=  -.12        R=   .32 *G     R=   .01       R=  -.09       R=   .00           55            25            39          0
             D= 15.09        D= 40.63        D=  9.73       D= 25.06       D=   .00

  39         R=  -.17        R=   .37 *G     R=  -.10       R=  -.07       R=  -.05           77            41            36          0
             D= 11.19        D= 60.10        D=  9.98       D=  9.73       D=   .24

  40         R=  -.11        R=  -.05        R=   .32 *G    R=  -.07       R=  -.05           66            31            36          0
             D= 19.46        D= 12.41        D= 46.23       D= 12.90       D=   .24

                                             KUDER-RICHARDSON RELIABILITY   =    .75
                                             STANDARD ERROR OF MEASUREMENT  =   2.89

                                             SPEARMAN-BROWN RELIABILITY     =    .74
                                             STANDARD ERROR OF MEASUREMENT  =   2.98
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ITEM ANALYSIS

Scrambled

ITEM	T	F				PERCENT CORRECT			DOUBLY
NO.	A	B	C	D	E	UPPER THIRD	LOWER THIRD	BLANKS	MARKED
1	R= .19 * D= 86.99	R= -.17 D= 6.85	R= -.09 D= 3.42	R= -.03 D= 2.74	R= .00 D= .00	95	81	0	0
2	R= -.14 D= 10.96	R= -.23 D= 14.38	R= .39 *G D= 65.75	R= -.20 D= 8.90	R= .00 D= .00	90	46	0	0
3	R= .38 *G D= 51.37	R= -.10 D= 10.27	R= -.29 D= 32.88	R= -.10 D= 5.48	R= .00 D= .00	55	31	0	0
4	R= -.20 D= 11.64	R= -.28 D= 12.33	R= .31 *G D= 63.01	R= -.00 D= 12.33	R= .00 D= .00	83	51	1	0
5	R= -.03 D= 8.22	R= -.17 D= 22.60	R= .38 *G D= 49.32	R= -.26 D= 19.18	R= .00 D= .00	74	27	1	0
6	R= -.15 D= 18.49	R= -.10 D= 45.89	R= -.09 D= 11.64	R= .31 * D= 23.29	R= .08 D= .68	39	6	0	0
7	R= .11 * D= 42.47	R= -.01 D= 26.03	R= -.11 D= 20.55	R= -.03 D= 10.96	R= .00 D= .00	49	39	0	0
8	R= -.12 D= 13.01	R= -.28 D= 19.86	R= -.20 D= 13.70	R= .46 *G D= 52.74	R= .00 D= .00	78	29	1	0
9	R= -.06 D= 6.85	R= -.06 D= 5.48	R= -.34 D= 41.78	R= .38 *G D= 45.21	R= .10 D= .68	68	27	0	0
10	R= -.17 D= 19.18	R= .29 *G D= 47.26	R= -.08 D= 21.23	R= -.12 D= 10.96	R= .00 D= .00	64	36	2	0
11	R= -.12 D= 9.59	R= -.02 D= 50.00	R= .03 D= 15.75	R= .08 * D= 24.66	R= .00 D= .00	30	17	0	0
12	R= -.13 D= 16.44	R= .15 D= 19.86	R= -.09 D= 41.78	R= .09 * D= 21.23	R= .00 D= .00	26	18	1	0
13	R= .20 * D= 28.77	R= -.21 D= 12.33	R= -.03 D= 21.92	R= -.00 D= 36.30	R= .00 D= .00	39	16	1	0
14	R= -.18 D= 6.85	R= -.12 D= 18.45	R= -.15 D= 23.97	R= .33 *G D= 50.00	R= .00 D= .00	68	31	1	0
15	R= .01 D= 15.75	R= .02 D= 30.82	R= -.12 D= 26.03	R= .08 * D= 26.71	R= .00 D= .00	23	21	0	1
16	R= -.05 D= 33.56	R= .05 D= 17.12	R= .02 * D= 36.30	R= -.01 D= 12.33	R= .00 D= .00	41	35	1	0
17	R= .12 * D= 38.36	R= -.10 D= 10.96	R= -.01 D= 34.25	R= -.06 D= 15.07	R= .00 D= .00	47	35	2	0

ITEM ANALYSIS
Scrambled

ITEM NO.	T A	F B	C	D	E	PERCENT CORRECT UPPER THIRD	 LOWER THIRD	BLANK	DOUBLY MARKED
18	R= -.06 D= 7.53	R= -.21 D= 20.55	R= -.04 D= 19.10	R= .23 * D= 52.74	R= .00 D= .00	67	37	0	0
19	R= .10 * D= 26.71	R= -.00 D= 37.67	R= -.12 D= 23.29	R= .02 D= 12.33	R= .00 D= .00	31	17	0	0
20	R= -.03 D= 15.07	R= .23 * D= 43.84	R= -.13 D= 12.33	R= -.11 D= 27.40	R= -.07 D= 1.37	56	30	0	0
21	R= -.04 D= 4.79	R= -.20 D= 7.53	R= -.43 D= 19.86	R= .50 *G D= 67.81	R= .00 D= .00	94	36	0	0
22	R= -.13 D= 6.16	R= -.07 D= 13.01	R= .16 * D= 54.11	R= -.05 D= 26.03	R= .00 D= .00	62	48	1	0
23	R= -.20 D= 6.85	R= -.14 D= 13.01	R= .27 *G D= 73.97	R= -.10 D= -.11	R= .10 D= .68	88	61	2	0
24	R= .06 D= 25.34	R= -.12 D= 26.71	R= .04 * D= 20.55	R= .02 D= 27.40	R= .00 D= .00	20	19	0	0
25	R= .01 D= 36.30	R= -.12 D= 28.77	R= -.19 D= 13.70	R= .30 * D= 20.55	R= .00 D= .00	35	13	1	0
26	R= .02 D= 16.44	R= -.16 D= 6.85	R= .18 * D= 54.79	R= -.14 D= 21.92	R= .00 D= .00	72	50	0	0
27	R= .01 D= 6.85	R= .33 *G D= 63.70	R= -.25 D= 18.49	R= -.21 D= 9.59	R= .00 D= .00	82	50	2	0
28	R= -.31 D= 26.71	R= -.23 D= 17.12	R= -.04 D= 16.44	R= .51 *G D= 37.67	R= .00 D= .00	72	13	3	0
29	R= -.15 D= 7.53	R= -.22 D= 12.33	R= -.21 D= 35.62	R= .48 *G D= 39.04	R= .00 D= .00	64	16	8	0
30	R= .08 D= 17.81	R= -.19 D= 34.25	R= -.03 D= 19.86	R= .17 * D= 23.97	R= .00 D= .00	29	22	6	0
31	R= -.02 D= 11.64	R= .09 * D= 44.52	R= -.07 D= 25.34	R= -.00 D= 15.75	R= .00 D= .00	51	45	4	0
32	R= -.12 D= 25.34	R= .24 * D= 40.41	R= -.03 D= 22.60	R= -.11 D= 6.16	R= .00 D= .00	50	29	8	0
33	R= -.17 D= 11.64	R= .00 D= 5.48	R= .21 * D= 27.40	R= -.01 D= 48.63	R= .00 D= .00	35	16	10	0
34	R= -.00 D= 15.75	R= .03 D= 24.66	R= .02 D= 31.51	R= .03 * D= 21.23	R= .00 D= .00	23	17	10	0

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                                                   ITEM ANALYSIS
                                                     Scrambled

 ITEM        T           F                                                     PERCENT CORRECT                   DOUBLY
 NO.         A           B           C           D           E          UPPER THIRD  LOWER THIRD     BLANKS    MARKED

  35     R=  -.14     R=   .04    R=   .09 *  R=   .02    R=   .03          39           32            9         0
         D= 10.96     D= 21.23    D= 38.36    D= 22.60    D=   .68

  36     R=  -.05     R=   .20 *  R=  -.04    R=  -.09    R=   .00          45           28           10         0
         D= 17.12     D= 34.25    D= 19.18    D= 22.60    D=   .00

  37     R=   .41 *A  R=  -.23    R=  -.20    R=  -.10    R=   .00          86           45            8         0
         D= 63.70     D= 13.01    D= 10.27    D=  7.53    D=   .00

  38     R=   .18 *   R=  -.29    R=   .11    R=   .16    R=  -.20          26           13           15         0
         D= 19.86     D= 31.51    D= 23.97    D= 13.70    D=   .68

  39     R=  -.09     R=  -.13    R=   .12    R=   .10 *  R=   .00          31           25           15         0
         D=  7.53     D= 19.18    D= 34.93    D= 28.08    D=   .00

  40     R=  -.19     R=  -.01    R=   .02    R=   .21 *  R=   .00          27           11           11         0
         D= 12.33     D= 25.34    D= 35.62    D= 19.18    D=   .00

                                  KUDER-RICHARDSON RELIABILITY   =    .55
                                  STANDARD ERROR OF MEASUREMENT  =   2.89

                                  SPEARMAN-BROWN RELIABILITY     =    .63
                                  STANDARD ERROR OF MEASUREMENT  =   2.63
```

APPENDIX E

Questionnaires

SCHOOL ______________________________

TEACHER ______________________________

INSTRUCTIONS: Please answer the following questions about the instructional packets.

1. When you were using the proportion (pink) packet, did you study all of the steps in the sample problems, or did you skip parts to finish more quickly? ______________________________.
Comments:

2. If yes, did you do this for all four packets, or more so towards the end of the year? ______________________________.
Comments:

3. If you used the proportion method, did you find it helpful? ______________________.
Comments:

4. You were assigned the proportion packet in solving problems. Did you actually use the proportion method? ______________________________.
Comments:

5. If you used another method instead of proportions, how did you learn the other method? ____.

6. If you used the proportion method but modified it some, how did you modify it?
____.

7. Did you ever borrow another person's packet of a different color, to learn how to do the problems? ______________________.

8. What did you like most about using these packets?
Comments:

9. What did you like least about using these packets?
Comments:

SCHOOL ____________________________

TEACHER ____________________________

INSTRUCTIONS: Please answer the following questions about the instructional packets.

1. When you were using the factor-label (yellow) packet, did you study all of the steps in the sample problems or did you skip parts to finish more quickly? ______ ____.
   Comments:

2. If yes, did you do this for all four packets, or more so towards the end of the year? ____________________________.
   Comments:

3. If you used the factor-label method, did you find it helpful? __________________.
   Comments:

4. You were assigned the factor-label packet in solving problems. Did you actually use the factor-label method? ______________________________.
   Comments:

5. If you used another method instead of factor-label, how did you learn the other method? ____.

6. If you used the factor-label method but modified it some, how did you modify it? ____.

7. Did you ever borrow another person's packet of a different color, to learn how to do the problems? ______________________________.

8. What did you like most about using these packets?
   Comments:

9. What did you like least about using these packets?
   Comments:

SCHOOL ____________________

TEACHER ____________________

INSTRUCTIONS: Please answer the following questions about the instructional packets.

1. When you were using the diagram (green) packet, did you really use the diagram or did you skip to the sample problems? ______________________________.
   Comments:

2. If yes, did you do this for all four packets, or more so towards the end of the year? ______________________.
   Comments:

3. If you used the diagrams, did you find them helpful? ____________________.
   Comments:

4. You were assigned the diagram packet in solving problems. Did you actually use the diagrams? ______________________.
   Comments:

5. If you used another method instead of diagrams, how did you learn the other method? ____.

6. If you used the diagram method but modified it some, how did you modify it?
   ____.

7. Did you ever borrow another person's packet of a different color, to learn how to do the problems? ______________________.

8. What did you like most about using these packets?
   Comments:

9. What did you like least about using these packets?
   Comments:

SCHOOL ____________________________

TEACHER ____________________________

INSTRUCTIONS: Please answer the following questions about the instructional packets.

1. When you were using the analogy (blue) packet, did you really use the analogies or did you skip to the sample problems? ______________________________________.
Comments:

2. If yes, did you do this for all four packets, or more so towards the end of the year? __________________________.
Comments:

3. If you used the analogies, did you find them helpful? _______________________.
Comments:

4. You were assigned the analogy packet in solving problems. Did you actually use the analogies? _____________________________.
Comments:

5. If you used another method instead of analogies, how did you learn the other method? ____.

6. If you used the analogy method but modified it some, how did you modify it?
____.

7. Did you ever borrow another person's packet of a different color, to learn how to do the problems? ______________________.

8. What did you like most about using these packets?
Comments:

9. What did you like least about using these packets?
Comments:

APPENDIX F

Teacher's Guides

Moles 513

Gas laws. 516

Stoichiometry 518

Molarity. 520

MOLES - TEACHER'S GUIDE

Lesson 1 - Mole as Particles

Prerequisite skills:

1. Students should be able to use scientific notation to represent large and small numbers and do simple mathematical manipulations.

2. Students should know the difference between elements and compounds.

Objectives:

Upon completion of the lesson the student should be able to:

1. Define the term mole in terms of the number of particles of a pure compound or element.

2. Calculate the number of particles of a substance, given the number of moles of the substance and the correct chemical formula.

3. Calculate the number of moles of a substance, given the number of particles and the correct chemical formula.

*Lesson 2 - The Mole as Mass

Prerequisite skills:

1. Completion of first lesson.

2. Students should be able to read a table of atomic masses or a periodic table.

3. Students should be able to determine the atomic or molecular mass of an element or compound. (These should be taught as a relative weight not as the weight of one mole).

Objectives:

Upon completion of the lesson the student should be able to:

1. Define the mole in terms of the mass of an element or pure compound.

2. Calculate the mass in grmas of one mole of an element or compound given the correct chemical formula and a chart of atomic masses.

3. Calculate the mass in grams of a given number of moles of a substance, given the correct chemical formula, and a chart of atomic masses.

4. Calculate the number of moles of a given mass of a substance, given the correct chemical formula, and a chart of atomic masses.

*Lesson 3 may be used before Lesson 2

Lesson 3 - The Mole as Volume

Prerequisite skills: same as first lesson.

Objectives:

Upon completion of the lesson the student should be able to:

1. Define the term mole in terms of the volume of an ideal gas at STP.
2. Calculate the volume of an ideal gas at STP, given the number of moles of the gas.
3. Calculate the moles of an ideal gas given the volume at STP.

Lesson 4 - Combination Problems

Prerequisite skills: same as first three lessons with addition of successful completion of the objectives of the first three lessons.

Objectives:

Upon completion of the lesson the student should be able to:

1. Given the correct chemical formula, a table of atomic masses, and any one of the following characteristics, calculate any of the other characteristics; mass in grams, moles, particles, and volume at STP if the substance is a gas.

Moles Keys

Lesson 1

1. C
2. D
3. B
4. C
5. D
6. B

Lesson 2

1. D
2. B
3. C
4. B

Lesson 3

1. C
2. B
3. D
4. C

Lesson 4

1. C
2. B
3. B
4. C
5. D
6. B

Test

1. C
2. B
3. D
4. C
5. A
6. C
7. B
8. B
9. D
10. C

TEACHER'S GUIDE--GAS LAWS

Lesson 1--Pressure and Volume (Boyle's Law)

Prerequisite skills:

1. Students should know that gases are composed of atoms or molecules that act as independent particles.
2. Students should know in a qualitative way that as the pressure of a gas increases, the volume decreases.

Objectives: Upon completion of the lesson, the student should be able to:

1. Predict the effect on a sample of gas if a volume or pressure change is made on the gas at constant temperature.
2. Calculate the new volume of a gas given a change in pressure at constant temperature.
3. Calculate the new pressure of a gas given a change in volume at constant temperature.

Lesson 2--Volume and Temperature (Charle's Law)

Prerequisite skills: Same as Lesson 1, plus:

1. Convert a temperature in degrees Celsius to degrees Kelvin and vice versa.
2. Students should know in a qualitative way that as the temperature of a gas increases, so does the volume.

Objectives: Upon completion of the lesson, the student should be able to:

1. Predict the effect on a sample of gas if a volume or temperature change is made on the gas at constant pressure.
2. Calculate the new volume of a gas given a change in Celsius temperature of constant pressure.
3. Calculate the new Celsius temperature of a gas given a change in volume at constant pressure.

Lesson 3--Combined Gas Law

Prerequisite skills: Same as Lessons 1 and 2.

Objectives: Upon completion of the lesson, the student should be able to:

1. Predict the effect of a change of temperature, pressure, and volume on a sample of gas.
2. Calculate the new volume of a gas given a change in pressure and temperature.
3. Calculate the new pressure of a gas given a change in volume and temperature.
4. Calculate the new Celsius temperature of a gas given a change in volume and pressure.

GAS LAWS KEYS

Gas Laws I Quiz Key

1. B
2. A
3. A
4. C

Gas Laws II Quiz Key

1. C
2. A
3. B
4. D

Gas Laws III Quiz Key

1. B
2. D
3. A
4. B

Gas Laws Test Key

1. B
2. B
3. A
4. D
5. A
6. B
7. A
8. C
9. C
10. C

LESSON 1: Particles-Particles, Moles-Moles, Volume-Volume

Prerequisite Skills:

1. Students should have completed the unit on moles.
2. Students should be able to balance simple chemical equations given the reactanct and products.

Objectives: After completion of the lesson the student should be able to:

1. Calculate the number of particles produced or which react when given a balanced chemical equation and the number of particles that react or are produced.
2. Calculate the moles produced or which react when given a balance chemical equation and the number of moles that react or are produced.
3. Calculate the volume at STP of gaseous products or reactants given a balanced chemical equation and the gaseous volume of either the reactants or products.

LESSON 2: Mass-Mass, Mass-Volume, Mass-Particles

Prerequisite Skills:

1. Same as day one.
2. Lesson 1 of this unit.

Objectives: After completion of the lesson the student should be able to:

1. Calculate the moles, gaseous volume, or number of particles of a chemical reaction given a balanced chemical equation, and the mass of either a reactant or product.

LESSON 3: Volume-Mass, Volume-Volume, Volume-Particles

Prerequisite Skills:

1. Same as day one.
2. Lesson 2 of this unit.

Objectives:

1. Calculate the mass, gaseous volume, or number of particles in a chemical reaction given a balanced equation and the gaseous volume of either on reactants or products.

Answer Key STOICHIOMETRY Quizzes and Test

Lesson 1

1. C
2. D
3. D
4. D

Lesson 2

1. C
2. C
3. A
4. B

Lesson 3

1. C
2. B
3. C
4. D

TEST

1. B
2. D
3. D
4. C
5. B
6. B
7. D
8. B
9. A
10. A

MOLARITY - TEACHER'S GUIDE

LESSON ONE: BASIC MOLARITY CALCULATIONS

Prerequisite Skills:

1. Student should be able to convert milliliters to liters and vice versa.
2. Student should be able to define the terms: solute, solvent and solution.

Objectives:

The student should be able to:

1. Calculate the molarity given the moles of solute and volume of solution.
2. Calculate the molarity given the mass of solute and volume of solution.
3. Calculate the moles of solute given the molarity and volume of solution.
4. Calculate the mass of solute given the molarity and volume of solution.
5. Calculate the volume of solution containing a specific mass of solute given the molarity.

LESSON TWO: DILUTION AND CONCENTRATION PROBLEMS

Prerequisite Skills:

1. Same as Lesson One.
2. Completion of Lesson One.

Objectives:

The student should be able to:

1. Calculate the new molarity when a solution of known molarity is diluted with a given volume of water.
2. Calculate the volume of water that must be added to a solution of known molarity to produce a solution of desired molarity.

3. Calculate the new molarity when a solution of known molarity is concentrated by boiling off a given volume of water.

4. Calculate the volume of water that must be boiled off from a solution of known molarity to produce a solution of desired molarity.

LESSON THREE: MOLARITY AND STOICHIOMETRY

Prerequisite Skills:

1. Sames as Lessons One and Two.

2. Completion of Stoichiometry Lessons.

Objectives:

The student should be able to:

1. Calculate the moles or mass of a reactant or product given the chemical reaction, molarity and volume of one of the reactants or products.

2. Calculate the molarity of a reactant or product solution given the chemical reaction, initial reactant or product molarity, initial volume and final volume of solution.

3. Calculate the volume of gas produced in a chemical reaction, at STP, given the chemical reaction, reactant molarity and reactant volume.

MOLARITY - QUIZ AND TEST KEY

LESSON I

1. B
2. C
3. B
4. A
5. B

LESSON II

1. D
2. C
3. B
4. C
5. B

LESSON III

1. B
2. A
3. B
4. A
5. B

TEST

1. B
2. A
3. A
4. C
5. D
6. B
7. B
8. C
9. A
10. D

APPENDIX G

Student Summary Sheets

Moles 524
Gas Laws. 528
Stoichiometry 532
Molarity. 536

REVEIW SHEET ON MOLES

Think of an analogy when solving a problem:

Compare number of particles in adozen to that of a mole.
Compare volume of a dozen to volume of a mole.
Compare mass of a dozen to mass of a mole.

eg. 1 dozen = 12 objects	1 mole = 6.02×10^{23} particles
1 dozen = 3 cu. ft.	1 mole = 22.4 liters
1 dozen oranges = a different mass than 1 dozen lemons	1 mole = at. wt. or mole. wt. in grams

eg. What is the volume of 5 dozen oranges if the volume of 1 dozen = 3 cu. ft.

$$5\ \cancel{\text{dozen}}\ \text{oranges} \times \frac{3\ \text{cu. ft.}}{1\ \cancel{\text{dozen}}} = 15\ \text{cu. ft. oranges}$$

Remember: 1 mole = 22.4 l and 1 mole = 6.02×10^{23} particles.

Problem: How many liters of CO_2 do 5 moles occupy?

Solution:

1. Compare this to volume of a number of dozen.

2. Set up problem using analogy.

$$5\ \text{dozen} \times \frac{3\ \text{cu. ft.}}{1\ \text{dozen}} = 15\ \text{cu. ft.}$$

3. Substitute chemicals.

$$5\ \text{moles}\ CO_2 \times \frac{22.4\ \text{l}}{1\ \text{mole}} = 112.0\ \text{l}\ CO_2$$

Problem: What is the mass of 3.01×10^{23} molecules of CO_2?

Note: Because moles are not given, this is a two step problem.

1. Compare to mass and particles in a dozen.

$$\frac{3{,}600\ \text{particles}}{12\ \text{particles/dozen}} = 300\ \text{dozen} \qquad \frac{3.01 \times 10^{23}\ \text{molecules}\ CO_2}{6.02 \times 10^{23}\ \text{molecules/mole}} = .5\ \text{mole}\ CO_2$$

REVIEW SHEET ON MOLES

When given a relationship, factors can be set up. Set up the factor so the units cancel.

eg. 12 in. = 1 ft. factor $\frac{12\ \text{in.}}{1\ \text{ft.}}$ or $\frac{1\ \text{ft.}}{12\ \text{in.}}$

How many in. are there in 100 ft.?

100 ft. x appropriate factor so units cancel

$$100\ \cancel{\text{ft}}. \times \frac{12\ \text{in.}}{1\ \cancel{\text{ft}}.} = 1200\ \text{ft.}$$

Remember: Relationship	Factor
1 mole = 22.4 l	$\frac{1\ \text{mole}}{22.4\ \text{l}}$ or $\frac{22.4\ \text{l}}{1\ \text{mole}}$
1 mole = 6.02×10^{23} particles	$\frac{1\ \text{mole}}{6.02 \times 10^{23}\ \text{particles}}$ or $\frac{6.02 \times 10^{23}\ \text{particles}}{1\ \text{mole}}$

Problem: How many liters of CO_2 do 5 moles occupy?

1. Write down the original relationship & multiply by factor. Cancel units.

$$5\ \cancel{\text{moles}}\ CO_2 \times \frac{22.4\ \text{l}}{1\ \cancel{\text{mole}}} = 112.0\ \text{l}\ CO_2$$

Problem: What is the mass of 3.01×10^{23} molecules of CO_2?

1. Write down first relationship converting to moles.

$$3.01 \times 10^{23}\ \text{mol}\cancel{\text{ecu}}\text{les}\ CO_2 \times \frac{1\ \text{mole}}{6.02 \times 10^{23}\ \text{mol}\cancel{\text{ecu}}\text{les}} = .50\ \text{moles}\ CO_2$$

2. Use answer obtained in step 1 for step 2 using new factor.

$$.50\ \text{mole}\ CO_2 \times \frac{44\ \text{g}}{1\ \text{mole}} = 22\ \text{g}\ CO_2$$

REVIEW SHEET ON MOLES

Set up problem so that unknown is in upper left of proportion, and other values are placed in correct places according to units.

eg. If 3 pencils cost 15¢, what is the cost of 10 pencils?

$$\frac{x\ (\text{cost})}{10\ \text{pencils}} = \frac{15¢}{3\ \text{pencils}}$$

Remember:

1 mole = 22.4 l

1 mole = 6.02×10^{23} particles

Problem: How many liters of CO_2 do 5 moles occupy?

1. Set up proportion.

$$\frac{x}{5\ \text{moles}} = \frac{22.4\ \text{l}}{1\ \text{mole}}$$

2. Cross multiply & solve.

$$X \cdot 1\ \text{mole} = 5\ \text{moles} \cdot 22.4\ \text{l}$$

$$x = 112.0\ \text{l}$$

Problem: What is the mass of 3.01×10^{23} molecules of CO_2?

1. Note that this is a two-step problem because moles are not given.
2. Set up first proportion by changing to moles, cross multiply, and solve.

$$\frac{x}{3.01 \times 10^{23}\ \text{molecules}\ CO_2} = \frac{1\ \text{mole}}{6.02 \times 10^{23}\ \text{molecules}}$$

$$X \cdot 6.02 \times 10^{23}\ \text{molecules} = 1\ \text{mole} \cdot 3.01 \times 10^{23}\ \text{molecules}\ CO_2$$

$$x = \frac{1\ \text{mole} \cdot 3.01 \times 10^{23}\ \text{molecules}\ CO_2}{6.02 \times 10^{23}\ \text{molecules}} = .50\ \text{mole}\ CO_2$$

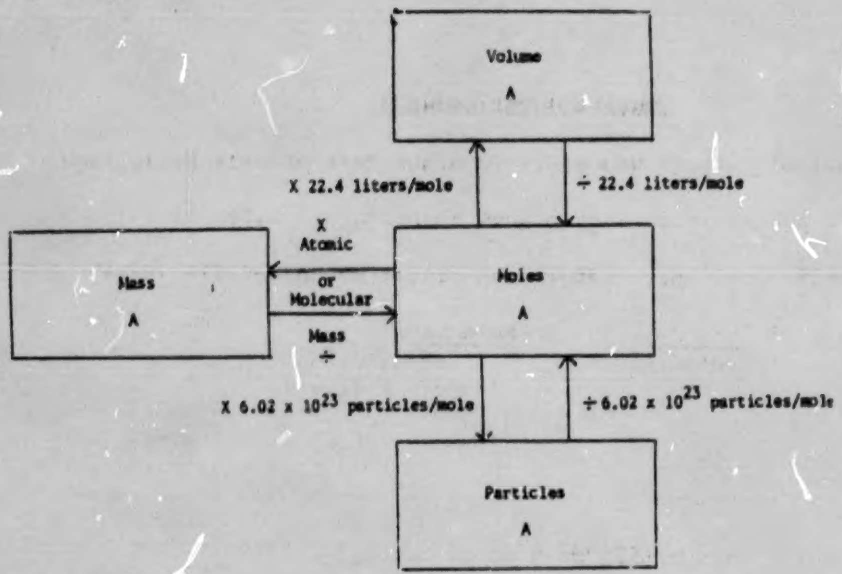
3. Set up second proportion using answer from the first. Cross multiply and solve.

$$\frac{x}{.50\ \text{mole}\ CO_2} = \frac{44\ \text{g}}{1\ \text{mole}}$$

$$X \cdot 1\ \text{mole} = 44\ \text{g} \cdot .50\ \text{mole}\ CO_2$$

$$x = \frac{44\ \text{g} \cdot .50\ \text{mole}}{1\ \text{mole}} = 22\ \text{g}\ CO_2$$

REVIEW SHEET ON MOLES


Volume
A
X 22.4 liters/mole
÷ 22.4 liters/mole
Mass
A
X Atomic or Molecular Mass ÷
Moles
A
X 6.02 x 10²³ particles/mole
÷ 6.02 x 10²³ particles/mole
Particles
A

Problem: How many liters of CO_2 do 5 moles occupy?

Solution:

1. Locate moles and volume on chart.

2. Use relationship for volume.

3. Set up problem.

$$5\ \cancel{\text{moles}}\ CO_2 \times \frac{22.4\ \text{l}}{1\ \cancel{\text{mole}}} = 112.0\ \text{l}\ CO_2$$

Problem: What's the mass of 3.01×10^{23} molecules of CO_2?

1. Locate molecules and mass on chart.

2. Note two relationships that must be used.

3. Set up problem in two steps.

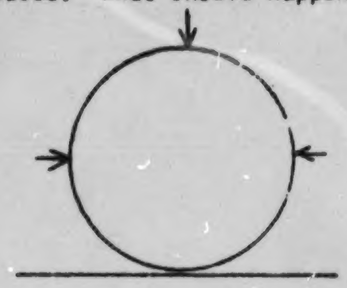
$$\frac{3.01 \times 10^{23}\ \text{mole}\cancel{\text{cules}}\ CO_2}{6.02 \times 10^{23}\ \text{mole}\cancel{\text{cules}}/\text{mole}} = .5\ \text{mole}\ CO_2$$

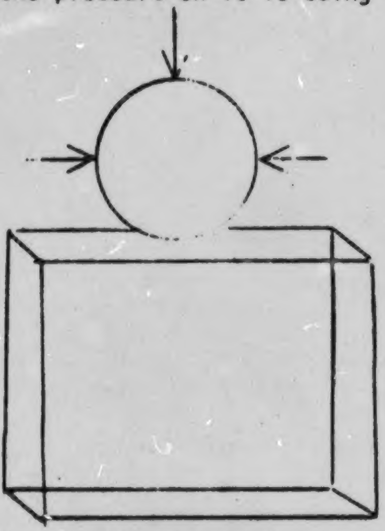
$$.5\ \text{mole}\ CO_2 \times \frac{(12 + 32)\text{g}\ CO_2}{1\ \text{mole}\ CO_2} = 22\text{g}\ CO_2$$

REVIEW SHEET ON GAS LAWS

Think of an analogy or example when solving a problem. The balloon example is particularly good when thinking about gases.

Example:
The balloon below is being cooled and the pressure on it is being increased. What should happen to the volume?





In gas law problems you must determine if the relationship is direct or inverse. (Pressure-Temperature = direct; Pressure-Volume = inverse).

If direct, set up so that an increase in one variable produces an increase in the other, and vice-versa.

If inverse, set up so that an increase in one variable produces a decrease in the other, and vice-versa.

Problem:
If 500 ml of a gas at 27°C and 1000 mm Hg is cooled to -127°C and subjected to a pressure of 2000 mm Hg, what would be the new volume?

Solution:

1. Determine the change in the variables:
   Temperature $27^\circ C \rightarrow -127^\circ C$ or $273^\circ + 27^\circ K \rightarrow 273^\circ + (-127^\circ)$
   or $300^\circ K \longrightarrow 146^\circ K$
2. Think of the example above to predict the new volume for each of the factors.
3. Set up the factors so as to increase or decrease the volume appropriately and do arithmetic.

$$500\text{ ml} \times \frac{146^\circ K}{300^\circ K} \times \frac{1000\text{ mm Hg}}{2000\text{ mm Hg}} = 122\text{ ml}$$

(The temperature decreases which causes a decrease in volume.) (The pressure increases which causes a decrease in volume.)

REVIEW SHEET ON GAS LAWS

When given a relationship, factors can be set up. Set up the factor so that the units cancel.

e.g. 12 in. = 1 ft. factor $\frac{12\text{ in.}}{1\text{ ft.}}$ or $\frac{1\text{ ft.}}{12\text{ in.}}$

How many inches are there in 100 ft.?

100 ft. × appropriate factor so units cancel.

$100\ \cancel{\text{ft.}} \times \frac{12\text{ in.}}{1\ \cancel{\text{ft.}}} = 1200\text{ ft.}$

In gas law problems you must determine if the relationship is direct or inverse. (Pressure-Temperature = direct; Pressure-Volume = inverse).

If direct, set up so that an increase in one variable produces an increase in the other, and vice-versa.

If inverse, set up so that an increase in one variable produces a decrease in the other, and vice-versa.

Problem:

If 500 ml of a gas at 27°C and 1000 mm Hg is heated to 127°C and subjected to a pressure of 2000 mm Hg, what would be the new volume?

Solution:

1. Determine the change in the variables.
   Temperature $27^\circ C \rightarrow 127^\circ C$ or $273^\circ + 27^\circ \rightarrow 273^\circ + 127^\circ$
   $300^\circ K \rightarrow 400^\circ K$
   Pressure $1000\text{ mm Hg} \rightarrow 2000\text{ mm Hg}$

2. Set up factors so as to increase or decrease volume appropriately and do arithmetic.

$$500\text{ ml} \times \underset{\uparrow}{\frac{400^\circ K}{300^\circ K}} \times \underset{\uparrow}{\frac{1000\ \cancel{\text{mm Hg}}}{2000\ \cancel{\text{mm Hg}}}} = 333\text{ ml}$$

(Temperature increases so volume increases (direct) larger temperature on top.)

(Pressure increases so volume decreases (inverse) so smallest pressure on top.)

REVIEW SHEET ON GAS LAWS

Set up the problem so that you work with a proportion.

e.q. If 3 pencils cost 15¢, what is the cost of 10 pencils?

$$\frac{x \text{ (cost)}}{10 \text{ pencils}} = \frac{15¢}{3 \text{ pencils}}$$

$$3x = 15¢ \cdot 10$$
$$3x = 150¢$$
$$x = 50¢$$

Because volume is directly related to temperature and inversely related to pressure, the following equation can be used to solve problems involving volume, pressure, and temperature.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Problem:

If 500 ml of a gas at 27°C and 1000 mm Hg is heated to 127°C and subjected to a pressure of 2000 mm Hg, what would its new volume be?

Solution:

1. Write formula $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

2. Substitute values in the equation.

$$\frac{(1000 \text{ mm Hg})\ (500 \text{ ml})}{(27 + 273^{\circ}\text{K})} = \frac{(2000 \text{ mm Hg})\ (V_2)}{(127 + 273^{\circ}\text{K})}$$

3. Solve by cross multiplication:

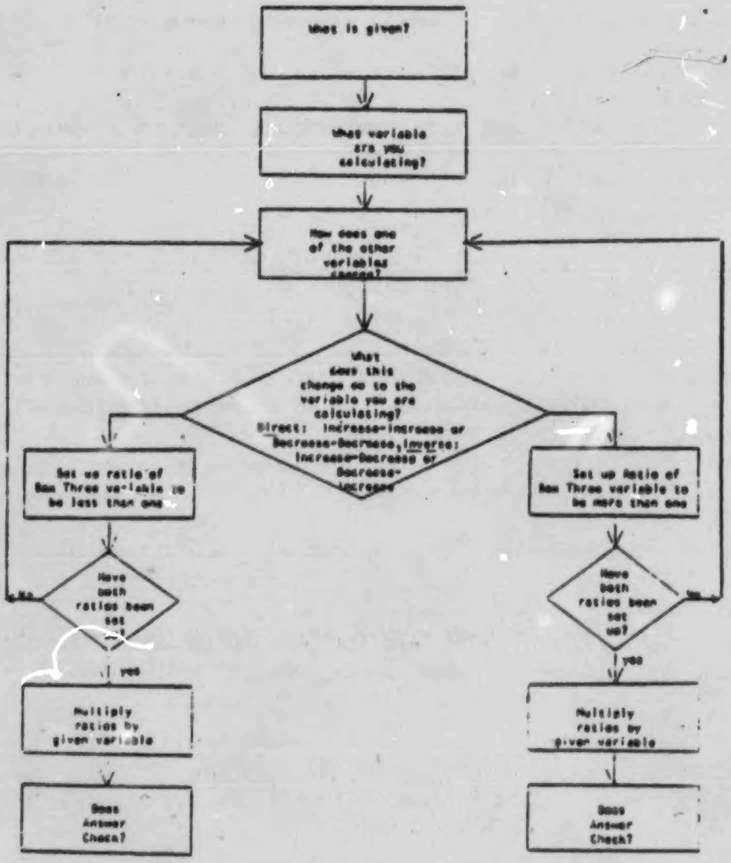
$$(1000 \text{ mm Hg})\ (500 \text{ ml})\ (400^{\circ}\text{K}) = (2000 \text{ mm Hg})\ (300^{\circ}\text{K})\ (V_2)$$

$$\frac{(\cancel{1000}\ \cancel{\text{mm Hg}})\ (500 \text{ ml})\ (\overset{2}{\cancel{400}}\cancel{^{\circ}\text{K}})}{(\underset{\underset{1}{\cancel{2}}}{\cancel{2000}}\ \cancel{\text{mm Hg}})\ (\underset{3}{\cancel{300}}\cancel{^{\circ}\text{K}})} = V_2$$

$$333 \text{ ml} = \frac{1000 \text{ ml}}{3} = V_2$$

REVIEW SHEET ON GAS LAWS

Diagram for Gas Laws


What is given?
What variable are you calculating?
How does one of the other variables change?
What does this change do to the variable you are calculating? Direct: Increase-Increase or Decrease-Decrease, Inverse: Increase-Decrease or Decrease-Increase
Set up ratio of Box Three variable to be less than one
Set up Ratio of Box Three variable to be more than one
Have both ratios been set up?
No
No
yes
yes
Multiply ratios by given variable
Multiply ratios by given variable
Does Answer Check?
Does Answer Check?

Problem:

If 500 ml of a gas at 27°C and 1000 mm Hg is heated to 127°C and subjected to a pressure of 2000 mm Hg, what would the new volume be?

Solution:

1. Note what is given: Volume: 500 ml
   Temperature: 27°C - 127°C
   Pressure: 1000 mm Hg - 2000 mm Hg
2. Note what you are calcualting: New volume.
3. Note how one other variable changes: Temperature increases.
4. Note what this does to volume: direct so increases
5. Set up ratio to increase - largest number on top.

$$\frac{127 + 273}{27 + 273} = \frac{400^\circ K}{300^\circ K}$$

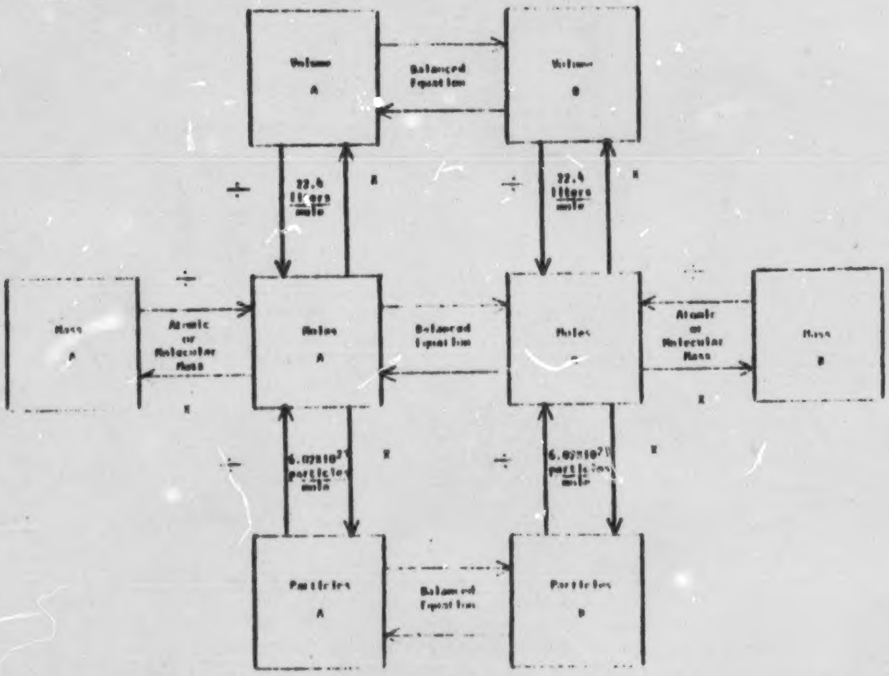
6. Only one ratio set-up, so now set up the other ratio.
7. Note that the other variable, pressure, increases.
8. Note what this does to volume: inverse so decreases.
9. Set up ratio to decrease - smallest number on top.

$$\frac{1000 \text{ mm Hg}}{2000 \text{ mm Hg}}$$

10. Work out problem.

$$500 \text{ ml} \times \frac{400\cancel{^\circ K}}{300\cancel{^\circ K}} \times \frac{1000 \cancel{\text{mm Hg}}}{2000 \cancel{\text{mm Hg}}} = 333 \text{ ml}$$

REVIEW SHEET ON STOICHIOMETRY


Volume A
Balanced Equation
Volume B
÷
22.4 liters/mole
x
÷
22.4 liters/mole
x
÷
Mass A
Atomic or Molecular Mass
x
Moles A
Balanced Equation
Moles B
÷
Atomic or Molecular Mass
x
Mass B
÷
6.02x10^23 particles/mole
x
÷
6.02x10^23 particles/mole
x
Particles A
Balanced Equation
Particles B

Problem:

How many grams of H_2O will be produced when 32.0 grams of CH_4 reacts with excess O_2 according to the reaction:

$CH_4\ (g)\ +\ 2\ O_2\ (g) \longrightarrow CO_2\ (g)\ +\ 2\ H_2O\ (g)$. Atomic masses; C= 12.0, H= 1.0, O= 16.0.

Solution:

1. Find moles CH_4: $\frac{32.0\ gr\cancel{a}ms\ CH_4}{16.0\ gr\cancel{a}ms/mole} = 2.0\ moles\ CH_4$

2. Find moles H_2O: $2.0\ mo\cancel{l}es\ C\cancel{H_4} \times \frac{2\ moles\ H_2O}{1\ mo\cancel{l}e\ \cancel{CH_4}} = 4.0\ moles\ H_2O$

3. Find grams H_2O: $4.0\ mo\cancel{l}es\ H_2O \times \frac{18.0\ grams}{1\ mo\cancel{l}e} = 72.0\ grams\ H_2O$

Problem:

How many molecules of CO_2 would be found if 100.8 liters of O_2 (measured at STP) reacted with excess CH_4 by the above reaction.

Solution using moles-moles method:

1. Find moles O_2: $\frac{100.8\ liters\ O_2}{22.4\ liters/mole} = 4.5\ moles\ O_2$

2. Find moles CO_2: $4.5\ mol\cancel{es\ O_2} \times \frac{1\ mole\ CO_2}{2\ mol\cancel{es\ O_2}} = 2.25\ moles\ CO_2$

3. Find molecules CO_2: $2.25\ \cancel{moles}\ CO_2 \times 6.02 \times 10^{23}\ \frac{molecules}{1\ \cancel{mole}} =$

13.5×10^{23} molecules CO_2

S-RA-1

REVIEW SHEET ON STOICHIOMETRY

Think of an analogy when solving a problem:

Compare number of particles in a dozen to that of a mole.
Compare volume of a dozen to volume of a mole.
Compare mass of a dozen to mass of a mole.
Compare "trading relationships" to balanced equation coefficients.

eg. 1 dozen = 12 objects 1 mole = 6.20×10^{23} particles

1 dozen = 3 cu. ft. 1 mole = 22.4 liters

1 dozen oranges = a different mass than 1 dozen lemons 1 mole = at. wt. or mole. wt. in grams

eg. What is the volume of 5 dozen oranges if the volume of 1 dozen = 3 cu. ft.?

$$5 \text{ dozen oranges} \times \frac{3 \text{ cu. ft.}}{1 \text{ dozen}} = 15 \text{ cu. ft. oranges}$$

Remember: 1 mole = 22.4 l and 1 mole = 6.02×10^{23} particles.

Problem:

How many grams of H_2O will be produced when 32.0 grams of CH_4 reacts with excess O_2 according to the reaction:

$CH_4\,(g) + 2\,O_2\,(g) \xrightarrow{} CO_2\,(g) + 2\,H_2O\,(g)$. Atomic masses; C = 12.0, H = 1.0, O = 16.0.

This problem is similar to the situation in which a trader wants to know how many grams of oranges he/she can obtain for 2400 grams of lemons if he/she knows that 1 dozen lemons may be traded for 2 dozen oranges and the weights of a dozen lemons and oranges are 1200 and 1500 grams respectively.

SOLUTIONS

Fruit Example	Chemistry Example
1. $\frac{2400 \text{ grams lemons}}{1200 \text{ grams/dozen}} = 2 \text{ doz. lemons}$	$\frac{32.0 \cancel{\text{grams}}\ CH_4}{16.0 \cancel{\text{grams}}\text{/mole}} = 2.0 \text{ moles } CH_4$
2. $2 \text{ doz. } \cancel{\text{lemons}} \times \frac{2 \text{ oranges}}{1 \cancel{\text{lemon}}}$	$2.0 \cancel{\text{moles } CH_4} \times \frac{2 \text{ moles } H_2O}{1 \cancel{\text{mole } CH_4}} = 4.0 \text{ moles } H_2O$
= 4 doz. oranges	
3. $4 \cancel{\text{doz.}} \text{ oranges} \times \frac{1500 \text{ grams}}{1 \cancel{\text{dozen}}}$	$4.0 \cancel{\text{moles}}\ H_2O \times \frac{18.0 \text{ grams}}{1 \cancel{\text{mole}}} = 72.0 \text{ grams } H_2O$
= 6000 grams oranges	

Problem:

How many molecules of CO_2 would be formed if 100.8 liters of O_2 (measured at STP) reacted with excess CH_4 by the above reaction.

This problem is similar to the situation in which a trader wants to know how many individual oranges he/she can obtain for 9 pints of lemons if 3 pints of fruit are equal to one dozen.

SOLUTIONS

Fruit Example	Chemistry Example
1. $\frac{9 \cancel{\text{pt.}} \text{ lemons}}{3 \cancel{\text{pt.}}\text{/doz.}} = 3 \text{ doz. lemons}$	$\frac{100.8 \cancel{\text{liters}}\ O_2}{22.4 \cancel{\text{liters}}\text{/mole}} = 4.5 \text{ moles } O_2$
2. $3 \text{ doz. } \cancel{\text{lemons}} \times \frac{2 \text{ oranges}}{1 \text{ lemon}}$	$4.5 \cancel{\text{moles } O_2} \times \frac{1 \text{ mole } CO_2}{2 \cancel{\text{moles } O_2}} = 2.25 \text{ moles } CO_2$
= 6 doz. oranges	
3. $6 \cancel{\text{doz.}} \text{ oranges} \times \frac{12}{1 \text{ doz}}$	$2.25 \cancel{\text{moles}}\ CO_2 \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \cancel{\text{mole}}}$
= 72 oranges	$= 13.5 \times 10^{23}$ molecules CO_2

S-RP-1

REVIEW SHEET ON STOICHIOMETRY

Set up problem so that unknown is in upper left of proportion, and other values are placed in correct places according to units.

eg. If 3 pencils cost 15¢, what is the cost of 10 pencils?

$$\frac{x\ (\text{cost})}{10\ \text{pencils}} = \frac{15¢}{3\ \text{pencils}}$$

Remember:

1 mole = 22.4 l

1 mole = 6.02×10^{23} particles

Remember to use the balanced equation coefficients to set up proportions when converting from moles x to moles y.

Problem:

How many grams of H_2O will be produced when 32.0 grams of CH_4 reacts with excess O_2 according to the reaction:
$CH_4\ (g) + 2\ O_2\ (g) \longrightarrow CO_2\ (g) + 2\ H_2O\ (g)$. Atomic masses:
C = 12.0, H = 1.0, O = 16.0.

Solution:

1. Find moles CH_4 from grams: $\frac{x}{32.0\ \text{grams}\ CH_4} = \frac{1\ \text{mole}}{16.0\ \text{grams}}$

$(x)\ (16.0\ \text{grams}) = (32.0\ \text{grams}\ CH_4)\ (1\ \text{mole})$

$$x = \frac{(32.0\ \text{grams}\ CH_4)\ (1\ \text{mole})}{(16.0\ \text{grams})} = 2.0\ \text{moles}\ CH_4$$

2. Find moles H_2O from equation: $\frac{x}{2.0\ \text{moles}\ CH_4} = \frac{2\ \text{moles}\ H_2O}{1\ \text{mole}\ CH_4}$

$(x)\ (1\ \text{mole}\ CH_4) = (2.0\ \text{moles}\ CH_4)\ (2\ \text{moles}\ H_2O)$

$$x = \frac{(2.0\ \cancel{\text{moles}\ CH_4})\ (2\ \text{moles}\ H_2O)}{1.0\ \cancel{\text{moles}\ CH_4}} = 4.0\ \text{moles}\ H_2O$$

3. Find grams H_2O from moles: $\frac{x}{4.0\ \text{moles}\ H_2O} = \frac{18.0\ \text{grams}}{1\ \text{mole}}$

$(x)\ (1\ \text{mole}) = (4.0\ \text{moles}\ H_2O)\ (18.0\ \text{grams})$

$$x = \frac{(4.0\ \cancel{\text{moles}\ H_2O})\ (18.0\ \text{grams})}{(1\ \cancel{\text{mole}})} = 72.0\ \text{grams}\ H_2O$$

Problem:

How many molecules of CO_2 would be formed if 100.8 liters of O_2 (measured at STP) reacted with excess CH_4 by the above reaction.

Solution:

1. Find moles O_2 from liters: $\frac{x}{100.8\ \text{liters}} = \frac{1\ \text{mole}}{22.4\ \text{liters}}$

$(x)\ (22.4\ \text{liters}) = (100.8\ \text{liters})\ (1\ \text{mole})$

$$x = \frac{(100.8\ \cancel{\text{liters}})\ (1\ \text{mole})}{(22.4\ \cancel{\text{liters}})} = 4.5\ \text{moles}\ O_2$$

2. Find moles CO_2 from equation: $\frac{x}{4.5\ \text{moles}\ O_2} = \frac{1\ \text{mole}\ CO_2}{2\ \text{moles}\ O_2}$

$(x)\ (2\ \text{moles}\ O_2) = (4.5\ \text{moles}\ O_2)\ (1\ \text{mole}\ CO_2)$

$$x = \frac{(4.5\ \cancel{\text{moles}\ O_2})\ (1\ \text{mole}\ CO_2)}{(2\ \cancel{\text{moles}\ O_2})} = 2.25\ \text{moles}\ CO_2$$

3. Find molecules CO_2 from moles: $\frac{x}{2.25\ \text{moles}\ CO_2} = \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mole}}$

$(x)\ (1\ \text{mole}) = (2.25\ \text{moles}\ CO_2)\ (6.02 \times 10^{23}\ \text{molecules})$

$$x = \frac{(2.25\ \cancel{\text{moles}}\ CO_2)\ (6.02 \times 10^{23}\ \text{molecules})}{(1\ \text{mole})} = 13.5 \times 10^{23}\ \text{molecules}\ CO_2$$

[illegible]

REVIEW SHEET ON STOICHIOMETRY

When given a relationship, factors can be set up. Set up the factor so the units cancel.

eq. 12 in. = 1 ft. factor: $\frac{12 \text{ in.}}{1 \text{ ft.}}$ or $\frac{1 \text{ ft.}}{12 \text{ in.}}$

How many in. are there in 100 ft.?

100 ft. x appropriate factor so units cancel

$100 \text{ ft.} \times \frac{12 \text{ in.}}{1 \text{ ft.}} = 1200 \text{ ft.}$

Remember: Relationship	Factor
1 mole = 22.4 l	$\frac{1 \text{ mole}}{22.4 \text{ l}}$ or $\frac{22.4 \text{ l}}{1 \text{ mole}}$
1 mole = 6.02×10^{23} particles	$\frac{1 \text{ mole}}{6.02 \times 10^{23} \text{ particles}}$ or $\frac{6.02 \times 10^{23} \text{ particles}}{1 \text{ mole}}$

Remember to use the balanced equation coefficients to set up factors when converting from moles x to moles y.

Problem:

How many grams of H_2O will be produced when 32.0 grams of CH_4 reacts with excess O_2 according to the reaction:

$CH_4\ (g) + 2\ O_2\ (g) \longrightarrow CO_2\ (g) + 2\ H_2O\ (g)$. Atomic masses: C = 12.0, H = 1.0, O = 16.0.

Solution:

1. Set up moles/gram CH_4 factor: $\frac{1 \text{ mole}}{16.0 \text{ grams}}$
2. Set up moles from equation factor: $\frac{2 \text{ moles } H_2O}{1 \text{ mole } CH_4}$
3. Set up grams/mole H_2O factor: $\frac{18.0 \text{ grams}}{1 \text{ mole}}$
4. Mulitplying factors by given quantity:

$$\overset{2}{32.0} \text{ grams } CH_4 \times \frac{1 \text{ mole}}{\underset{1}{16.0} \text{ grams}} \times \frac{2 \text{ moles } H_2O}{1 \text{ mole } CH_4} \times \frac{18.0 \text{ grams}}{1 \text{ mole}} = 72.0 \text{ grams}$$

Problem:

How many molecules of CO_2 would be found if 100.8 liters of O_2 (measured at STP) reacted with excess CH_4 by the above reaction.

Solution:

1. Set up moles/liters O_2 factor: $\frac{1 \text{ mole}}{22.4 \text{ liters}}$
2. Set up moles from equation factor: $\frac{1 \text{ mole } CO_2}{2 \text{ moles } O_2}$
3. Set up molecules/mole CO_2 factor: $\frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mole}}$
4. Multiply factors by given quantity:

$$100.8 \text{ liters } O_2 \times \frac{1 \text{ mole}}{22.4 \text{ liters}} \times \frac{1 \text{ mole } CO_2}{2 \text{ moles } O_2} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mole}}$$

$$= 13.5 \times 10^{23} \text{ molecules } CO_2$$

Name:____________________________________

Period or small group:______________________

Please answer the following questions by circling the correct answer. In order to get full credit for question five, you must show your work. Remember to set up factors whenever possible to help solve the problems.

Example: A jet can travel 500 miles per hour, how many hours would a trip of 2500 miles take?

$$2500\ \cancel{\text{miles}} \times \frac{1\ \text{hour}}{500\ \cancel{\text{miles}}} = 5\ \text{hours}$$

1. What would be the molarity of a solution made by boiling off 500 ml of water from 2500 ml of a 2.0 M NaCl solution?

A. 0.40 M
B. 0.625 M
C. 1.67 M
D. 2.50 M

2. What would be the molarity of a solution made by adding 1.0 liter of water to 2.0 liters of a 3.0 M NaCl solution?

A. 0.22 M
B. 0.50 M
C. 2.0 M
D. 6.0 M

3. How many milliliters of water must be added to 750 ml of a 1.25 M NaCl solution to reduce the molarity to 0.50 M?

A. 217 ml
B. 1125 ml
C. 2583 ml
D. 2625 ml

4. What would be the molarity of a solution made by adding 850 ml of water to 1400 ml of a 2.6 M NaCl solution?

A. 0.62 M
B. 0.83 M
C. 1.62 M
D. 6.62 M

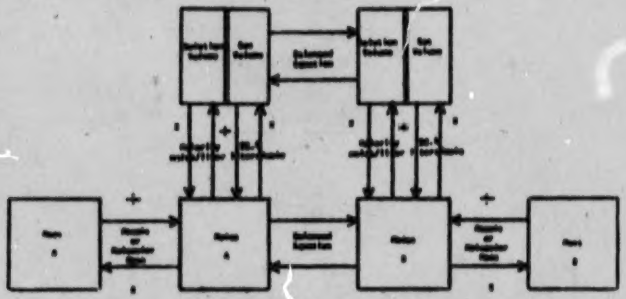
5. How many milliliters of water must be boiled away from 1200 ml of 1.6 M NaCl to produce a 2.0 M NaCl solution?

A. 160 ml
B. 240 ml
C. 533 ml
D. 2160 ml

Name:____________________________________ Mo-III-QD-I

Period or small group:_______________________

Please answer the following questions by circling the correct answer. In order to get full credit for question five, you must show your work.



Questions one through four deal with the following balanced reaction:

$2\ HCl_{(aq)} + Mg(OH)_{2(aq)} \longrightarrow MgCl_{2(aq)} + 2\ H_2O_{(l)}$

Molecular Masses: $HCl = 36.5$; $Mg(OH)_2 = 58.3$; $MgCl_2 = 95.3$; $H_2O = 18.0$

1. How many moles of magnesium chloride ($MgCl_2$) would be produced when 2.0 liters of 1.0 M hydrochloric acid (HCl) reacts with a sufficient amount of magnesium hydroxide $Mg(OH)_2$?

   A. 0.5 mole B. 1.0 mole

   C. 2.0 moles D. 4.0 moles

2. How many grams of magnesium hydroxide ($Mg(OH)_2$) are needed to react completely with 500 ml of a 1.20 M hydrochloric acid (HCl) solution?

   A. 17.5 grams B. 70.0 grams

   C. 194.3 grams D. 279.8 grams

3. What would be the molarity of 1500ml of magnesium chloride ($MgCl_2$) solution formed when 1200 ml of a 4.0 M hydrochloric acid solution reacts with sufficient magnesium hydroxide ($Mg(OH)_2$)?

   A. 0.10 M B. 1.6 M

   C. 3.2 M D. 6.4 M

4. How many moles of magnesium chloride ($MgCl_2$) would be produced when 1800 ml of 0.36 M hydrochloric acid (HCl) reacts with a sufficient amount of magnesium hydroxide $Mg(OH)_2$?

   A. 0.32 mole B. 0.65 mole

   C. 1.30 moles D. 2.50 moles

5. Sodium carbonate (Na_2CO_3) will react with hydrochloric acid (HCl) to form sodium chloride (NaCl), water (H_2O) and carbon dioxide (CO_2). How many liters of CO_2 (measured at STP) will be produced when 300 ml of 6.0 M HCl reacts with sufficient Na_2CO_3? Reaction: $Na_2CO_{3\ (s)} + 2\ HCl_{(aq)} \longrightarrow 2\ NaCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$

   A. 2.24 liters B. 20.2 liters

   C. 74.7 liters D. 224 liters

Mo-I-QA-1

Name: ______________________________

Period or small group: __________________

Please answer the following questions by circling the correct answer. In order to get full credit for question five you must show your work. Try to think of the analogy of soup as you work the problems. Example: What would be the dozarity of a soup made by adding 5 dozen pieces of corn in enough soup to make 2 liters?

$$\frac{\text{5 dozen corn}}{\text{2 liters}} = \frac{\text{2.5 dozen}}{\text{liter}} = \text{2.5 dozarity}$$

All of the following questions deal with the substance potassium chloride (KCl) which has a molecular mass of 74.6 grams per mole.

1. What would be the molarity of a solution made by dissolving 6.0 moles of potassium chloride (KCl) in enough water to make 3.0 liters of solution?

   A. 0.5 M B. 2.0 M

   C. 3.0 M D. 6.0 M

2. What would be the molarity of a solution made by dissolving 149.2 grams of KCl in enough water to make 1200 ml of solution?

   A. 0.42 M B. 0.60 M

   C. 1.67 M D. 2.40 M

3. How many grams of KCl would be present in 1600 ml of a 0.50 M KCl solution?

   A. 23.3 grams B. 59.7 grams

   C. 93.3 grams D. 238.7 grams

4. What would be the molarity of a solution made by dissolving 0.45 moles of KCl in enough water to make 1400 ml of solution?

   A. 0.32 M B. 3.1 M

   C. 28.0 M D. 35.7 M

5. How many milliliters of a 1.6 M KCl solution would contain 14.9 grams of KCl?

   A. 8.0 ml B. 125 ml

   C. 320 ml D. 3125 ml

APPENDIX H

Summary Tables of Multiple Regression Analyses

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* * * * * * * * * * * * * * * * * * * * * * * * M U L T I P L E   R E G R E S S I O N   * * * * * * * * * * * * * * * * * * * * * * * *
DEPENDENT VARIABLE..   MOOT

                                            S U M M A R Y   T A B L E

STEP      VARIABLE                 F TO        SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R        OVERALL F   SIGNIFICANCE
      ENTERED   REMOVED      ENTER OR REMOVE                                       CHANGE

  1   VVOV                        .23975          .425         .00790     .00006    .00006   -.00790           .59388        .553
      VVOI                       1.15496          .283         .04751     .00226    .00219    .04245
  2   MARSTOT                   12.95994          .000         .16229     .02634    .02408   -.14776          4.72492        .003
  3   PPRT                      43.27938          .000         .31742     .10075    .07441    .29691         14.64946        .000
  4   X3                        16.00505          .000         .35054     .12288    .02213   -.15062         11.11105        .000
      X2                          .04870          .825         .35234     .12414    .00126   -.04548
      X1                         3.56925          .059         .36071     .13011    .00597   -.00504
  5   VX2                        3.07748          .080         .36349     .13213    .00201   -.02649          6.27455        .000
      VX1                         .72142          .396         .36538     .13350    .00138   -.01233
      VX3                         .15735          .692         .36583     .13383    .00033   -.14211
      IX3                         .00485          .944         .36643     .13427    .00044   -.15230
      IX2                        1.58714          .208         .36944     .13649    .00222   -.05072
      IX1                         .28179          .596         .37008     .13696    .00047   -.01001
  6   MX1                         .03160          .859         .37058     .13733    .00037   -.00499          5.10253        .000
      MX3                         .00216          .963         .37062     .13736    .00003   -.13835
      MX2                         .23622          .627         .37116     .13776    .00040   -.03964
  7   PX2                         .68097          .410         .37128     .13785    .00009   -.04013          4.47920        .000
      PX1                        1.43229          .232         .37719     .14228    .00443    .01415
      PX3                         .72071          .396         .37880     .14349    .00122   -.13870
  8   VIX1                       4.10122          .043         .39213     .15377    .01028   -.02214          4.51300        .000
      VIX3                       4.56405          .033         .39614     .15693    .00316   -.14276
      VIX2                       4.45832          .035         .40534     .16430    .00738   -.03650
  9   VMX1                       1.87869          .171         .41241     .17008    .00578   -.00848          4.05153        .000
      VMX2                        .89558          .344         .41565     .17277    .00269   -.01650
      VMX3                        .03259          .857         .41603     .17308    .00031   -.13163
      IMX1                       6.47710          .011         .42612     .18157    .00849   -.01457
      IMX3                       2.08306          .150         .43037     .18522    .00364   -.14006
      IMX2                        .00701          .933         .43038     .18523    .00001   -.04569
 10   VPX2                       1.40256          .237         .43306     .18754    .00231   -.02417          3.81373        .000
      VPX1                       3.06800          .080         .44264     .19593    .00839   -.00747
      VPX3                       2.73664          .099         .44737     .20014    .00421   -.12983
      IPX1                       3.02439          .083         .45314     .20534    .00519    .00050
      IPX3                        .59197          .442         .45335     .20553    .00019   -.14248
      IPX2                       1.69013          .194         .45634     .20824    .00271   -.04701
 11   PMX1                       1.68331          .195         .46237     .21379    .00554    .00962          3.62101        .000
      PMX2                        .01076          .917         .46242     .21384    .00005   -.03712
      PMX3                        .54877          .459         .46337     .21472    .00088   -.13430
 12   VIMX1                       .06801          .794         .46362     .21494    .00023   -.02214          3.39466        .000
      VIMX3                       .03748          .847         .46414     .21543    .00048   -.13393
      VIMX2                      1.62213          .203         .46694     .21803    .00260   -.02862
 13   VIPX1                       .03618          .849         .46696     .21805    .00002   -.02167          3.18021        .000
      VIPX2                       .54432          .461         .46710     .21818    .00012   -.03856
      VIPX3                      1.31488          .252         .46936     .22030    .00212   -.13254
 14   VPMX1                      4.16533          .042         .47570     .22629    .00599   -.01114          2.93391        .000
      VPMX2                       .14914          .700         .47625     .22681    .00053   -.02149
      VPMX3                       .00924          .923         .47625     .22682    .00000   -.12787
      IPMX1                      1.55709          .213         .47921     .22964    .00282   -.00861
      IPMX2                       .67123          .413         .47990     .23031    .00067   -.04437
      IPMX3                       .56441          .453         .48085     .23122    .00091   -.13845
 15   VIPMX1                     1.64397          .200         .48107     .23143    .00021   -.02911          2.83725        .000
      VIPMX2                      .02196          .882         .48208     .23240    .00097   -.03351
      VIPMX3                     2.86036          .091         .48682     .23699    .00459   -.13212
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609

608

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* * * * * * * * * * * * * * * * * * * * *   M U L T I P L E   R E G R E S S I O N   * * * * * * * * * * * * * * * * * * * * *
DEPENDENT VARIABLE..    GLOT

                                                S U M M A R Y   T A B L E

STEP       VARIABLE                  F TO      SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R        OVERALL F   SIGNIFICANCE
      ENTERED   REMOVED         ENTER OR REMOVE                                     CHANGE

  1   VVQV                          .79827        .372         .02356     .00056    .00056   -.02356         1.00398        .367
      VVQI                         1.72253        .190         .06250     .00391    .00335    .04851
  2   MARSTOT                     10.59443        .001         .15537     .02414    .02023   -.13131         4.21334        .006
  3   PPRT                        16.26515        .000         .23302     .05430    .03016    .19840         7.32069        .000
  4   X3                          28.40915        0            .27100     .07344    .01914    .13915         8.91363        0
      X2                           7.47057        .006         .31310     .09803    .02459   -.06369
      X1                           6.57608        .011         .33103     .10958    .01155   -.06103
  5   VX2                           .55013        .459         .33181     .11010    .00051   -.05190         9.96235        0
      VX1                           .29970        .584         .33337     .11114    .00104   -.06251
      VX3                           .06088        .805         .33353     .11124    .00011    .13223
      IX3                           .03937        .843         .33551     .11257    .00133    .12816
      IX2                           .14928        .699         .33660     .11330    .00073   -.06971
      IX1                           .43941        .508         .33775     .11407    .00078   -.07231
  6   MX1                          4.61575        .032         .35151     .12363    .00955   -.03702         4.40187        .000
      MX3                           .00000        .999         .35166     .12366    .00003    .14374
      MX2                           .13646        .712         .35200     .12390    .00024   -.05478
  7   PX2                           .34352        .558         .35348     .12495    .00105   -.05121         3.87866        0
      PX1                          2.09297        .149         .35634     .12698    .00203   -.04777
      PX3                          1.48078        .224         .35998     .12959    .00260    .11572
  8   VIX1                         1.31461        .252         .36629     .13416    .00457   -.07599         3.69002        .000
      VIX3                         2.37449        .124         .36798     .13541    .00125    .12224
      VIX2                         3.56601        .060         .37634     .14163    .00622   -.05322
  9   VMX1                          .07524        .784         .37641     .14168    .00005   -.04303         2.97838        .000
      VMX2                          .04508        .799         .37656     .14180    .00011   -.04634
      VMX3                          .08779        .767         .37688     .14204    .00024    .13909
      IMX1                          .66888        .414         .38114     .14527    .00323   -.05096
      IMX3                          .00825        .928         .38142     .14548    .00021    .13216
      IMX2                          .56033        .454         .38270     .14646    .00098   -.06347
 10   VPX2                          .54601        .460         .38458     .14790    .00144   -.04432         2.57272        .000
      VPX1                          .20722        .649         .38521     .14838    .00049   -.05407
      VPX3                         1.12398        .290         .38736     .15005    .00166    .10650
      IPX1                         1.77674        .183         .38908     .15138    .00134   -.06199
      IPX3                          .09328        .760         .39012     .15220    .00081    .10685
      IPX2                         1.10549        .294         .39261     .15414    .00195   -.05748
 11   PMX1                          .54835        .459         .39850     .15880    .00466   -.03079         2.60904        .000
      PMX2                         5.33955        .021         .40971     .16786    .00906   -.05267
      PMX3                          .24138        .409         .41026     .16832    .00046    .12126
 12   VIMX1                         .02983        .863         .41057     .16856    .00025   -.05926         2.43806        .000
      VIMX3                         .00355        .953         .41136     .16922    .00065    .12701
      VIMX2                         .81169        .368         .41309     .17064    .00142   -.06096
 13   VIPX1                        5.26624        .022         .41908     .17563    .00499   -.07055         2.40371        .000
      VIPX2                         .38825        .534         .42185     .17796    .00233   -.05459
      VIPX3                        1.14792        .285         .42421     .17996    .00200    .10009
 14   VPMX1                         .31045        .578         .42423     .17997    .00001   -.04047
      VPMX2                         .07889        .779         .42477     .18043    .00046   -.04687         2.16032        .000
      VPMX3                         .14667        .683         .42493     .18057    .00013    .11459
      IPMX1                        1.82324        .178         .42908     .18411    .00354   -.04725
      IPMX2                         .47648        .490         .42967     .18461    .00050   -.06061
      IPMX3                         .46708        .495         .43062     .18543    .00082    .11097
 15   VIPMX1                        .78250        .377         .43293     .18742    .00199   -.05957
      VIPMX2                        .49368        .483         .43349     .18791    .00049   -.05995         2.06192        .000
      VIPMX3                        .25742        .612         .43401     .18836    .00045    .10384
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DEPENDENT VARIABLE..   SQT

                                              S U M M A R Y   T A B L E

STEP      VARIABLE              F TO       SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R        OVERALL F   SIGNIFICANCE
     ENTERED  REMOVED     ENTER OR REMOVE                                     CHANGE

  1  VVQV                      .03552        .951       .02053    .00042    .00042    .02053          .50464        .604
     VVQI                      .78764        .375       .04380    .00192    .00150    .04303
  2  MARSTOT                 13.11081        .000       .16212    .02628    .02436   -.15442         4.71446        .003
  3  PPRT                    42.04282        0          .31422    .09873    .07245    .29334        14.32350        .000
  4  X3                        .93172        .335       .32261    .10409    .00534   -.07533         8.75023        .000
     X2                        .61180        .434       .32459    .10536    .00128   -.06877
     X1                        .01252        .911       .32462    .10538    .00002   -.05393
  5  VX2                       .11243        .738       .32555    .10579    .00060   -.07189         4.77094        .000
     VX1                       .19197        .661       .32562    .10603    .00004   -.05854
     VX3                       .21288        .645       .32643    .10656    .00053   -.06817
     IX3                       .06291        .802       .32643    .10656    .00000   -.07320
     IX2                       .63890        .424       .32787    .10750    .00094   -.07242
     IX1                       .10208        .749       .32814    .10767    .00018   -.05550
  6  MX1                      2.25583        .134       .33347    .11121    .00353   -.04045         4.07059        .000
     MX3                       .19113        .662       .33349    .11121    .00001   -.06178
     MX2                      1.05532        .305       .33622    .11305    .00183   -.06616
  7  PX2                       .00408        .949       .33800    .11424    .00120   -.05179         3.57423        .000
     PX1                      1.88764        .170       .34338    .11791    .00367   -.03146
     PX3                       .00342        .953       .34339    .11792    .00001   -.07194
  8  VIX1                      .00845        .927       .34421    .11848    .00056   -.05627         3.14756        .000
     VIX3                      .19130        .662       .34421    .11848    .00000   -.06452
     VIX2                     1.20846        .272       .34726    .12059    .00210   -.07079
  9  VMX1                      .01638        .898       .34796    .12108    .00049   -.05256         2.97434        .000
     VMX2                     1.11991        .290       .34859    .12151    .00044   -.07144
     VMX3                      .94138        .332       .34994    .12246    .00095   -.06321
     IMX1                     2.80853        .094       .36747    .13504    .01257   -.04896
     IMX3                      .43893        .508       .36747    .13504    .00000   -.06299
     IMX2                     4.65235        .031       .37819    .14303    .00799   -.07599
 10  VPX2                      .05848        .809       .37869    .14340    .00038   -.05414         2.58465        .000
     VPX1                      .35619        .551       .38344    .14703    .00362   -.04402
     VPX3                      .01197        .913       .38344    .14703    .00000   -.06520
     IPX1                     2.25307        .134       .38703    .14979    .00276   -.03789
     IPX3                      .01601        .899       .38744    .15011    .00032   -.06898
     IPX2                      .69120        .410       .38895    .15129    .00117   -.05190
 11  PMX1                      .51862        .472       .39190    .15391    .00222   -.02366         2.47205        .000
     PMX2                     2.18195        .140       .39561    .15691    .00300   -.05816
     PMX3                      .46022        .498       .39661    .15730    .00079   -.06245
 12  VIMX1                     .93527        .334       .39716    .15774    .00043   -.05565         2.31291        .000
     VIMX3                     .15443        .695       .39870    .15896    .00122   -.06231
     VIMX2                     .39560        .530       .39955    .15964    .00068   -.07479
 13  VIPX1                    1.53795        .216       .39998    .15998    .00034   -.04495         2.21844        .000
     VIPX2                    1.85827        .173       .40563    .16453    .00455   -.04976
     VIPX3                     .06329        .801       .40576    .16464    .00011   -.06112
 14  VPMX1                    3.91172        .049       .41341    .17091    .00627   -.04544         2.19716        .000
     VPMX2                     .59848        .440       .41547    .17261    .00170   -.06052
     VPMX3                     .21375        .644       .41636    .17336    .00075   -.06450
     IPMX1                    1.95532        .163       .42261    .17860    .00524   -.03607
     IPMX2                    2.48336        .116       .42662    .18200    .00340   -.06128
     IPMX3                     .64724        .414       .42795    .18314    .00114   -.06204
 15  VIPMX1                    .08768        .767       .42796    .18315    .00000   -.05046         2.06025        .000
     VIPMX2                    .05464        .815       .42799    .18318    .00003   -.05874
     VIPMX3                    .50001        .480       .42899    .18404    .00086   -.06252
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DEPENDENT VARIABLE..     MLCT


                                                   S U M M A R Y   T A B L E

STEP       VARIABLE                      F TO      SIGNIFICANCE  MULTIPLE R   R SQUARE   R SQUARE   SIMPLE R          OVERALL F     SIGNIFICANCE
       ENTERED   REMOVED             ENTER OR REMOVE                                        CHANGE

  1    VVZ4                              .03607        .849          .03628     .00132     .00132     .03628           5.77147          .003
       VVZ1                            10.85558        .001          .15371     .02363     .02231     .15347
  2    MARSICT                          7.41909        .007          .19650     .03861     .01498    -.11943           6.37245          .000
  3    FFAT                            32.51039           0          .31766     .10091     .06229     .28569          13.32734          .000
  4    X3                               3.24745        .072          .33411     .11163     .01072    -.10927           8.57832          .000
       X2                                .58107        .446          .33523     .11238     .00075    -.07740
       X1                                .25604        .613          .33595     .11286     .00048    -.05021
  5    VX2                               .86531        .353          .33792     .11419     .00133    -.05654           4.75056          .000
       VX1                               .50262        .479          .33957     .11531     .00112    -.05189
       VX3                               .00365        .952          .33959     .11532     .00001    -.09602
       IX3                               .31342        .576          .34172     .11677     .00145    -.09749
       IX2                               .08342        .773          .34204     .11699     .00022    -.06574
       IX1                               .01307        .909          .34208     .11702     .00002    -.04807
  6    MX1                               .05575        .813          .34214     .11706     .00004    -.05526           3.87206          .000
       MX3                               .03400        .854          .34262     .11739     .00033    -.10621
       MX2                               .33035        .566          .34353     .11802     .00063    -.08306
  7    FX2                               .03133        .860          .34415     .11844     .00042    -.05784           3.39234          .000
       FX1                              2.27854        .132          .35028     .12270     .00426    -.02671
       FX3                               .10532        .746          .35057     .12290     .00020    -.10194
  8    VIX1                              .24677        .620          .35125     .12338     .00048    -.05129           3.06777          .000
       VIX3                             1.16684        .280          .35720     .12759     .00421    -.09037
       VIX2                              .56578        .451          .35872     .12868     .00109    -.05149
  9    VMX1                              .16595        .684          .35940     .12917     .00049    -.06363           2.70555          .000
       VMX2                              .01116        .916          .36003     .12962     .00045    -.06780
       VMX3                             1.35923        .244          .36214     .13115     .00153    -.10324
       IMX1                             2.73764        .099          .36523     .13340     .00225    -.05693
       IMX3                             5.45602        .020          .37848     .14325     .00985    -.09264
       IMX2                              .29923        .585          .37923     .14382     .00057    -.07298
 10    VFX2                              .34044        .560          .37957     .14407     .00026    -.03860           2.34562          .000
       VFX1                             2.84126        .093          .38351     .14708     .00301    -.03707
       VFX3                             1.57956        .209          .38851     .15094     .00386    -.08626
       IFX1                              .07365        .786          .38874     .15112     .00018    -.02878
       IFX3                              .27174        .602          .38907     .15138     .00026    -.09064
       IFX2                              .31546        .575          .38984     .15198     .00060    -.05144
 11    PMX1                             2.03352        .155          .39249     .15405     .00207    -.03556           2.21924          .000
       PMX2                              .88235        .348          .39556     .15647     .00242    -.06434
       PMX3                              .10375        .747          .39581     .15667     .00020    -.10124
 12    VIMX1                            1.61632        .204          .39662     .15731     .00064    -.06592           2.15505          .000
       VIMX3                            2.55148        .111          .40512     .16412     .00681    -.09514
       VIMX2                             .00702        .933          .40513     .16413     .00001    -.06322
 13    VIPX1                             .16331        .686          .40685     .16553     .00140    -.03856           2.07030          .000
       VIPX2                            2.02613        .155          .41042     .16844     .00291    -.03674
       VIPX3                             .58632        .444          .41178     .16956     .00112    -.08059
 14    VPMX1                             .36900        .544          .41406     .17145     .00199    -.05333           1.86539          .001
       VPMX2                             .01648        .898          .41406     .17145     .00000    -.04958
       VPMX3                             .18011        .689          .41449     .17181     .00036    -.09618
       IFMX1                             .00236        .961          .41496     .17219     .00039    -.04113
       IFMX2                            1.40683        .236          .41863     .17525     .00305    -.05790
       IFMX3                             .02857        .865          .41869     .17530     .00006    -.08817
 15    VIPMX1                           3.35418        .068          .42081     .17709     .00178    -.05769           1.85347          .001
       VIPMX2                            .31548        .572          .42445     .18016     .00307    -.04731
       VIPMX3                           2.09046        .149          .42913     .18415     .00399    -.08822
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DEPENDENT VARIABLE..     PCT

                                              S U M M A R Y   T A B L E

STEP        VARIABLE                  F TO       SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R        OVERALL F   SIGNIFICANCE
       ENTERED    REMOVED      ENTER OR REMOVE                                      CHANGE

  1    VVCV                          .25626         .613        .04164    .00173    .00173    .04164          1.41714       .243
       VVCI                         1.51854         .167        .07328    .00537    .00364    .06989
  2    MARSTCT                      5.48316         .020        .12518    .01567    .01030   -.10340          2.78055       .040
  3    PPPT                        67.46890          0          .35797    .12814    .11247    .35347         19.21717       .000
  4    X3                           1.35919         .237        .36742    .13500    .00685   -.08601         11.69411       .000
       X2                            .33410         .564        .36857    .13585    .00085   -.06892
       X1                            .09821         .754        .36880    .13601    .00016   -.06803
  5    VX2                           .10554         .745        .36881    .13602    .00001   -.06347          6.47611       .000
       VX1                           .00387         .950        .36838    .13607    .00005   -.06325
       VX3                           .00315         .955        .36894    .13612    .00005   -.08135
       IX3                           .11423         .736        .37048    .13726    .00114   -.09062
       IX2                          2.01812         .156        .37402    .13989    .00263   -.07738
       IX1                           .50737         .477        .37515    .14074    .00085   -.07066
  6    MX1                           .50745         .477        .37612    .14147    .00073   -.06266          5.29515       .000
       MX3                           .44212         .506        .37691    .14206    .00059   -.08073
       MX2                           .05336         .760        .37712    .14222    .00016   -.06316
  7    PX2                           .55227         .458        .37729    .14235    .00013   -.06068          4.68350       .000
       PX1                          3.02526         .083        .38591    .14892    .00657   -.04128
       PX3                           .08076         .776        .38608    .14906    .00014   -.08186
  8    VIX1                          .00000         .999        .38655    .14942    .00036   -.06505          4.05457       .000
       VIX3                          .26184         .609        .38741    .15008    .00066   -.08555
       VIX2                          .02024         .887        .38745    .15012    .00003   -.07039
  9    VPX1                         3.62234         .058        .38960    .15179    .00167   -.06070          3.57368       .000
       VPX2                         3.97180         .047        .39663    .15731    .00552   -.06524
       VPX3                          .17068         .680        .39744    .15796    .00064   -.08096
       IPX1                         5.00595         .026        .40560    .16451    .00655   -.07016
       IPX3                         1.26414         .261        .40867    .16701    .00250   -.08538
       IPX2                          .01329         .908        .40870    .16703    .00002   -.07276
 10    VMX2                          .68801         .407        .41011    .16819    .00116   -.05744          3.16987       .000
       VMX1                         1.74129         .188        .41575    .17285    .00466   -.04953
       VMX3                          .97383         .324        .41886    .17545    .00260   -.07553
       IMX1                         1.67403         .196        .41980    .17623    .00078   -.04879
       IMX3                          .39495         .530        .42181    .17792    .00169   -.08333
       IMX2                          .88376         .348        .42355    .17939    .00147   -.06574
 11    PMX1                          .36357         .547        .42357    .17941    .00002   -.03855          2.96190       .000
       PMX2                          .86288         .353        .42665    .18203    .00262   -.05937
       PMX3                          .44870         .503        .42752    .18278    .00075   -.08215
 12    VIMX1                         .88865         .346        .42766    .18289    .00011   -.06555          2.80244       .000
       VIMX3                         .00175         .967        .42887    .18393    .00104   -.08617
       VIMX2                        1.90464         .168        .43256    .18711    .00318   -.07462
 13    VIPX1                         .01805         .893        .43277    .18729    .00018   -.05327          2.61278       .000
       VIPX2                         .02240         .881        .43285    .18736    .00007   -.06138
       VIPX3                         .61545         .432        .43405    .18840    .00104   -.07716
 14    VPMX1                        3.00612         .084        .43518    .18938    .00098   -.05127          2.54166       .000
       VPMX2                        4.09909         .043        .43954    .19320    .00382   -.06237
       VPMX3                         .39111         .532        .44041    .19396    .00076   -.08115
       IPMX1                        7.37344         .007        .45175    .20408    .01011   -.05080
       IPMX2                         .63111         .427        .45366    .20581    .00173   -.06560
       IPMX3                         .53500         .465        .45464    .20669    .00089   -.08401
 15    VIPMX1                        .96770         .326        .45598    .20791    .00122   -.05750          2.41456       .000
       VIPMX2                        .26848         .605        .45601    .20794    .00003   -.06864
       VIPMX3                        .67470         .412        .45724    .20907    .00112   -.08398
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DEPENDENT VARIABLE..    GLT

                                                        S U M M A R Y   T A B L E

STEP       VARIABLE                    F TO      SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE   SIMPLE R          OVERALL F   SIGNIFICANCE
      ENTERED   REMOVED          ENTER OR REMOVE                                      CHANGE

  1   VVQV                           1.59069         .208        .04485     .00201    .00201    -.04485          1.00720        .366
      VVQI                            .94040         .323        .06260     .00392    .00191     .02571
  2   MARSTOT                        6.83225         .009        .13062     .01706    .01314    -.10116          2.95653        .032
  3   PPRT                          36.96659         .009        .28895     .08349    .06643     .27351         11.61512        .000
  4   X3                             4.10631         .043        .28928     .08368    .00019     .01259          8.17320         0
      X2                             6.62578         .010        .31606     .09989    .01621    -.10330
      X1                              .85206         .356        .31844     .10140    .00151    -.06233
  5   VX2                             .00851         .927        .31844     .10140    .00000    -.09778          4.75774         0
      VX1                            2.92807         .088        .32072     .10266    .00146    -.07252
      VX3                            2.95687         .086        .32675     .10676    .00390     .02504
      IX3                             .87110         .351        .32787     .10750    .00074     .00868
      IX2                             .16722         .683        .32787     .10750    .00000    -.10422
      IX1                            1.46096         .227        .33190     .11009    .00260    -.06265
  6   MX1                             .00014         .991        .33190     .11016    .00006    -.06479          3.85836        .000
      MX3                             .01241         .911        .33191     .11016    .00001     .01125
      MX2                             .21324         .644        .33248     .11055    .00038    -.10440
  7   PX2                             .24942         .618        .33249     .11055    .00000    -.09329          3.51146        .000
      PX1                            1.47243         .226        .33309     .11095    .00040    -.05300
      PX3                            4.39411         .037        .34464     .11877    .00782    -.01576
  8   VIX1                            .11451         .735        .34543     .11932    .00055    -.07209          3.05059        .000
      VIX3                            .36737         .545        .34603     .11974    .00041     .02115
      VIX2                            .16785         .682        .34647     .12004    .00030    -.09804
  9   VMX1                            .30337         .582        .34650     .12006    .00002    -.07986          2.51683        .000
      VMX2                            .18864         .664        .34733     .12064    .00058    -.10095
      VMX3                            .27974         .597        .34778     .12095    .00031     .02279
      IMX1                            .07341         .787        .34852     .12147    .00051    -.06750
      IMX3                           2.29747         .130        .35571     .12653    .00506     .00392
      IMX2                            .06127         .805        .35586     .12664    .00011    -.10689
 10   VPX2                            .55689         .455        .35961     .12932    .00268    -.08240          2.29587        .000
      VPX1                            .22010         .639        .36368     .13226    .00294    -.06845
      VPX3                            .03340         .855        .36399     .13249    .00023    -.00415
      IPX1                           1.10627         .293        .36505     .13326    .00078    -.05792
      IPX3                            .50239         .479        .36508     .13328    .00002    -.02065
      IPX2                           3.68076         .056        .37400     .13988    .00660    -.08451
 11   PMX1                            .11314         .737        .37446     .14022    .00034    -.05524          2.19504        .000
      PMX2                           2.45032         .119        .37793     .14283    .00261    -.10024
      PMX3                           1.49576         .223        .38144     .14549    .00266    -.01565
 12   VIMX1                           .31183         .577        .38198     .14591    .00041    -.08124          2.02863        .000
      VIMX3                           .00963         .922        .38200     .14593    .00002     .01592
      VIMX2                           .13514         .713        .38232     .14617    .00024    -.10289
 13   VIPX1                          1.53918         .215        .38242     .14624    .00007    -.07084          1.95966        .000
      VIPX2                           .29100         .594        .38581     .14885    .00261    -.07780
      VIPX3                          1.97869         .160        .39040     .15241    .00356    -.00542
 14   VPMX1                           .00472         .945        .39387     .15513    .00272    -.07900          1.85478        .001
      VPMX2                           .30334         .582        .39487     .15593    .00079    -.09144
      VPMX3                          1.72513         .190        .39864     .15891    .00299    -.00659
      IPMX1                          1.27580         .259        .39924     .15939    .00048    -.06418
      IPMX2                          1.29644         .255        .40333     .16267    .00328    -.09738
      IPMX3                           .45620         .500        .40435     .16350    .00082    -.02246
 15   VIPMX1                          .26793         .605        .40602     .16485    .00135    -.08284          1.76271        .001
      VIPMX2                          .15045         .698        .40604     .16487    .00002    -.08802
      VIPMX3                          .37766         .539        .40688     .16555    .00068    -.01176
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DEPENDENT VARIABLE..   ST

                                          S U M M A R Y   T A B L E

STEP      VARIABLE                    F TO      SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R        OVERALL F   SIGNIFICANCE
      ENTERED   REMOVED        ENTER OR REMOVE                                    CHANGE

  1   VVQV                         .10976          .741          .02192    .00048    .00048   -.02192           .25383        .776
      VVQI                         .25523          .614          .03108    .00097    .00049   -.02752
  2   MARSTOT                    19.34656          .000          .19115    .03654    .03557   -.18232          6.62398        .000
  3   PPRT                       48.52555             0          .34401    .11834    .08180    .30438         17.54996        .000
  4   X3                           .00379          .951          .34435    .11857    .00023   -.01729         10.39703        .000
      X2                          1.01205          .315          .34513    .11912    .00054    .01083
      X1                          2.14994          .141          .35039    .12278    .00366   -.05018
  5   VX2                         1.04875          .306          .35039    .12278    .00000    .00930          6.00525        .000
      VX1                         4.08717          .044          .35888    .12880    .00602   -.07238
      VX3                          .00753          .931          .35889    .12880    .00001   -.02523
      IX3                          .04230          .803          .35999    .12959    .00079   -.01329
      IX2                          .29092          .590          .36005    .12964    .00005    .01293
      IX1                         1.31095          .253          .36312    .13186    .00221   -.04672
  6   MX1                          .13708          .711          .36524    .13340    .00154   -.06016          5.11006        .000
      MX3                          .60120          .439          .36533    .13347    .00007   -.01403
      MX2                         2.64580          .104          .37139    .13793    .00446   -.00501
  7   PX2                          .73080          .393          .37351    .13951    .00158    .03118          4.36396        .000
      PX1                          .29330          .589          .37379    .13972    .00020   -.03010
      PX3                          .35455          .552          .37459    .14032    .00060   -.02216
  8   VIX1                         .06698          .796          .37548    .14099    .00067   -.06416          3.77660        .000
      VIX3                         .01457          .904          .37565    .14112    .00013   -.01874
      VIX2                         .09744          .755          .37587    .14128    .00017    .01414
  9   VMX1                         .00121          .972          .37597    .14136    .00008   -.08531          3.06813        .000
      VMX2                        1.24641          .265          .37693    .14208    .00072   -.00468
      VMX3                         .62183          .431          .37812    .14297    .00090   -.02702
      IMX1                         .01564          .901          .37862    .14335    .00038   -.05906
      IMX3                         .04030          .841          .37877    .14347    .00012   -.01155
      IMX2                        1.99069          .159          .38324    .14687    .00340   -.00527
 10   VPX2                         .00704          .933          .38331    .14692    .00005    .02882          2.58519        .000
      VPX1                         .20151          .654          .38350    .14707    .00015   -.05470
      VPX3                         .62786          .429          .38523    .14840    .00133   -.03234
      IPX1                         .82281          .365          .38851    .15094    .00254   -.03112
      IPX3                         .21421          .644          .38889    .15124    .00030   -.02020
      IPX2                         .04408          .834          .38899    .15131    .00008    .03265
 11   PMX1                         .90361          .342          .38928    .15154    .00023   -.03880          2.41969        .000
      PMX2                         .09803          .754          .39051    .15250    .00096    .01219
      PMX3                        1.14944          .284          .39305    .15449    .00198   -.02158
 12   VIMX1                        .60226          .439          .39314    .15456    .00007   -.07821          2.26693        .000
      VIMX3                        .43930          .509          .39567    .15655    .00199   -.02235
      VIMX2                        .23945          .625          .39619    .15697    .00041   -.00214
 13   VIPX1                       1.15979          .282          .39638    .15711    .00014   -.05013          2.19606        .000
      VIPX2                        .23371          .629          .39662    .15731    .00019    .03332
      VIPX3                       3.43864          .064          .40405    .16325    .00594   -.02665
 14   VPMX1                        .26280          .608          .40574    .16463    .00138   -.06766          2.00985        .000
      VPMX2                        .01973          .889          .40625    .16504    .00041    .01231
      VPMX3                        .22494          .636          .40716    .16578    .00074   -.03750
      IPMX1                        .02444          .876          .40721    .16582    .00004   -.04264
      IPMX2                       2.88806          .090          .41281    .17042    .00460    .01249
      IPMX3                        .24108          .624          .41332    .17083    .00042   -.02085
 15   VIPMX1                       .19096          .662          .41400    .17140    .00056   -.06429          1.89195        .000
      VIPMX2                       .08652          .769          .41407    .17146    .00006    .01542
      VIPMX3                       .07124          .799          .41422    .17158    .00012   -.03348
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DEPENDENT VARIABLE..     MLT

                                                  S U M M A R Y   T A B L E

STEP      VARIABLE                  F TO       SIGNIFICANCE  MULTIPLE R   R SQUARE   R SQUARE   SIMPLE R          OVERALL F    SIGNIFICANCE
     ENTERED  REMOVED         ENTER OR REMOVE                                         CHANGE

  1  VVCV                           .00035         .985        .00364     .00001     .00001     .00364            .05645          .945
     VVCI                           .10659         .744        .01538     .00024     .00022     .01536
  2  MARSTCT                      11.27934         .001        .15290     .02338     .02314    -.14926           3.79823          .010
  3  PFRT                         30.79042           0         .28780     .08283     .05945     .26367          10.72456          .000
  4  X3                             .94961         .330        .29663     .08799     .00516    -.07420           6.63631          .000
     X2                             .04792         .827        .29665     .08800     .00001    -.04037
     X1                             .82037         .363        .29933     .08960     .00160    -.07244
  5  VX2                            .35928         .549        .30007     .09004     .00044    -.04517           3.91218          .000
     VX1                            .21014         .647        .30075     .09045     .00041    -.08034
     VX3                           1.10121         .295        .30431     .09261     .00216    -.08786
     IX3                            .04615         .830        .30432     .09261     .00000    -.07619
     IX2                           2.70864         .100        .31039     .09634     .00373    -.04999
     IX1                           1.06285         .303        .31369     .09840     .00206    -.07225
  6  MX1                           1.56686         .208        .31568     .09965     .00125    -.06438           3.31922          .000
     MX3                            .00001         .998        .31634     .10007     .00042    -.06629
     MX2                           1.46138         .227        .32078     .10290     .00283    -.04719
  7  PX2                            .02053         .886        .32212     .10376     .00086    -.02755           3.00960          .000
     PX1                           3.43101         .065        .33205     .11025     .00649    -.04349
     PX3                            .16070         .689        .33251     .11057     .00031    -.07216
  8  VIX1                          1.31276         .252        .33696     .11355     .00298    -.08292           2.67794          .000
     VIX3                           .31857         .573        .33760     .11398     .00043    -.08869
     VIX2                           .11278         .737        .33793     .11419     .00022    -.05314
  9  VMX1                           .75260         .374        .33832     .11446     .00026    -.07626           2.43987          .000
     VMX2                          4.79009         .029        .34887     .12171     .00725    -.05945
     VMX3                           .77219         .380        .35165     .12366     .00195    -.08298
     IMX1                           .05644         .812        .35281     .12448     .00082    -.06317
     IMX3                          2.86203         .091        .36240     .13133     .00686    -.06428
     IMX2                           .11317         .737        .36270     .13155     .00022    -.05485
 10  VPX2                          4.40550         .036        .37821     .14304     .01149    -.01793           2.33202          .000
     VPX1                          1.65230         .199        .38562     .14870     .00566    -.05660
     VPX3                           .10192         .750        .38591     .14893     .00022    -.07978
     IPX1                           .28381         .594        .38595     .14896     .00003    -.04731
     IPX3                           .00003         .996        .38623     .14917     .00022    -.07209
     IPX2                          1.07826         .300        .38888     .15123     .00206    -.03118
 11  PMX1                           .24374         .622        .38893     .15127     .00004    -.03796           2.19748          .000
     PMX2                           .63577         .426        .38917     .15145     .00018    -.03710
     PMX3                          2.05023         .153        .39417     .15537     .00392    -.06274
 12  VIMX1                          .02693         .870        .39514     .15613     .00076    -.07761           2.05249          .000
     VIMX3                          .00075         .978        .39564     .15653     .00039    -.08075
     VIMX2                          .53306         .466        .39693     .15755     .00102    -.06610
 13  VIPX1                          .03556         .851        .39693     .15755     .00000    -.06093           1.96420          .000
     VIPX2                         1.30944         .253        .39815     .15853     .00097    -.02120
     VIPX3                         1.95390         .163        .40284     .16228     .00375    -.07844
 14  VPMX1                          .75210         .386        .40285     .16229     .00001    -.05476           1.79659          .001
     VPMX2                          .71144         .399        .40617     .16497     .00268    -.03589
     VPMX3                         1.21163         .272        .41003     .16812     .00315    -.07540
     IPMX1                          .09751         .755        .41013     .16820     .00008    -.04103
     IPMX2                          .60810         .436        .41106     .16897     .00077    -.03951
     IPMX3                          .50032         .480        .41223     .16994     .00097    -.06009
 15  VIPMX1                         .02901         .865        .41223     .16994     .00000    -.05814           1.68400          .003
     VIPMX2                         .05845         .809        .41248     .17014     .00021    -.03821
     VIPMX3                         .01825         .893        .41253     .17018     .00004    -.07208
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DEPENDENT VARIABLE..   ACSTCT

                                          S U M M A R Y   T A B L E

STEP      VARIABLE                  F TO          SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE   SIMPLE R        OVERALL F   SIGNIFICANCE
      ENTERED   REMOVED      ENTER OR REMOVE                                          CHANGE

  1   VVCV                          .00043            .984       .01212    .00015    .00015     .01212          .51061        .600
      VVCI                          .94358            .332       .04405    .00194    .00179     .04405
  2   MARSTCT                     16.34464            .000       .17925    .03213    .03019    -.16996         5.75657        .001
  3   PERT                       125.00890              0        .46781    .21885    .18671     .45540        36.63036        .000
  4   X2                            .55826            .455       .46805    .21907    .00023     .01144        20.94803        .000
      X3                            .05176            .820       .46838    .21938    .00030    -.00884
      X1                            .39180            .532       .46900    .21996    .00059    -.02221
  5   VX2                          3.57972            .059       .47184    .22264    .00267     .01165        12.33560        .000
      VX1                           .75384            .37[illegible]       .47276    .22351    .00087    -.00417
      VX3                          2.24580            .135       .47467    .22531    .00181     .01117
      IX3                          2.32685            .128       .47495    .22558    .00026     .01373
      IX2                          7.92063            .005       .48740    .23756    .01199    -.02103
      IX1                           .15977            .690       .48765    .23780    .00024    -.02468
  6   MX1                           .00143            .970       .48768    .23783    .00003    -.03032         9.97625        .000
      MX3                           .00102            .975       .48769    .23784    .00001     .01657
      MX2                           .11888            .730       .48787    .23802    .00018    -.01514
  7   PX2                           .61131            .435       .49328    .24333    .00531     .01717         8.72953        .000
      PX1                           .29394            .588       .49469    .24472    .00139     .00377
      PX3                           .95671            .328       .49612    .24614    .00142     .02208
  8   VIX1                          .69381            .405       .49708    .24708    .00095    -.00755         7.53960        .000
      VIX3                          .01839            .892       .49717    .24718    .00009     .01207
      VIX2                          .04734            .828       .49724    .24725    .00007     .00195
  9   VMX1                         1.00973            .315       .49924    .24924    .00200    -.01285         6.19342        .000
      VMX2                          .03232            .857       .49971    .24971    .00047     .00725
      VMX3                          .17121            .679       .50012    .25012    .00041     .01423
      IMX1                         4.60021            .032       .50756    .25762    .00750    -.03792
      IMX3                          .00953            .921       .50764    .25770    .00008     .01599
      IMX2                          .13599            .712       .50784    .25790    .00020    -.02787
 10   VPX2                          .67022            .413       .50937    .25946    .00156     .03269         5.32644        .000
      VPX1                         2.92331            .088       .51154    .26167    .00221     .01010
      VPX3                         1.99708            .158       .51587    .26612    .00445     .02333
      IPX1                          .01093            .917       .51652    .26680    .00068     .00021
      IPX3                         1.16203            .282       .51831    .26864    .00184     .02667
      IPX2                          .00747            .931       .51832    .26865    .00001     .00912
 11   PMX1                         3.02894            .082       .51971    .27010    .00144    -.00711         5.08617        .000
      PMX2                          .18148            .670       .51992    .27032    .00022     .01124
      PMX3                         4.86014            .028       .52677    .27749    .00717     .02958
 12   VIMX1                         .65048            .420       .52685    .27757    .00008    -.02055         4.82096        .000
      VIMX3                        1.76223            .185       .53205    .28308    .00551     .01120
      VIMX2                         .39285            .531       .53259    .28365    .00058    -.00443
 13   VIPX1                        1.10634            .293       .53375    .28489    .00123     .00617         4.50153        .000
      VIPX2                         .47873            .489       .53448    .28567    .00079     .02547
      VIPX3                         .00549            .941       .53449    .28568    .00001     .02556
 14   VPMX1                        2.91743            .088       .53937    .28984    .00416    -.00272         4.07552        .000
      VPMX2                        1.75521            .186       .53929    .29084    .00100     .02838
      VPMX3                         .83560            .361       .54042    .29206    .00122     .02645
      IPMX1                        1.51306            .219       .54208    .29385    .00179    -.01608
      IPMX2                         .42628            .514       .54279    .29463    .00078     .00096
      IPMX3                         .02217            .858       .54284    .29467    .00005     .03127
 15   VIPMX1                        .45968            .498       .54366    .29557    .00090    -.01100         3.87515        .000
      VIPMX2                       1.40138            .237       .54463    .29662    .00105     .01865
      VIPMX3                        .84093            .360       .54577    .29786    .00124     .02484
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* * * * * * * * * * * * * * * * * * * * * * MULTIPLE REGRESSION
DEPENDENT VARIABLE..   ACSR

                                   SUMMARY TABLE

STEP     VARIABLE                F TO       SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R       OVERALL F  SIGNIFICANCE
     ENTERED  REMOVED      ENTER OR REMOVE                                       CHANGE

  1  VVCV                       .16101        .688         .03089    .00095    .00095    .03089         .25524       .745
     VVCI                       .23309        .630         .03970    .00158    .00062    .03386
  2  MARSICT                   5.03437        .003         .15870    .02519    .02361    .15545        3.71251       .023
  3  PPRT                     73.55836        .000         .43142    .18612    .16093    .42136       21.25766       .000
  4  X2                         .19326        .660         .43144    .18614    .00002    .01959       12.41805       0
     X1                         .25718        .612         .43144    .18614    .00000    .02178
     X3                        2.05832        .152         .43665    .19066    .00451    .05893
  5  VX2                       2.62397        .106         .43831    .19212    .00146    .03749        7.39353       0
     VX1                        .35527        .549         .43886    .19260    .00048    .03997
     VX3                       1.54673        .214         .44049    .19403    .00143    .05363
     IX1                        .00052        .982         .44094    .19442    .00040    .01781
     IX2                       6.66218        .010         .45314    .20534    .01091    .00471
     IX3                       1.84314        .175         .45755    .20935    .00401    .05837
  6  MX1                        .06954        .792         .45770    .20949    .00014    .01557        5.97378       .000
     MX3                        .00070        .979         .45771    .20950    .00001    .06265
     MX2                        .00626        .937         .45772    .20951    .00001    .01297
  7  PX2                        .14627        .702         .45813    .20988    .00037    .02934        5.11577       0
     PX1                        .01536        .901         .45913    .21080    .00091    .03720
     PX3                       1.51531        .219         .46275    .21413    .00334    .06177
  8  VIX1                       .02461        .875         .46280    .21418    .00005    .03905        4.39993       .000
     VIX2                       .01131        .915         .46302    .21439    .00021    .02704
     VIX3                       .15113        .698         .46339    .21473    .00034    .05427
  9  VMX1                       .58390        .445         .46435    .21562    .00089    .03212        3.50350       .000
     VMX2                       .22285        .637         .46446    .21572    .00010    .03222
     VMX3                       .13154        .717         .46474    .21598    .00026    .05407
     IMX1                      1.56605        .212         .46806    .21908    .00310    .00740
     IMX2                       .33806        .561         .46894    .21990    .00082    .00233
     IMX3                       .00070        .979         .46894    .21990    .00000    .05864
 10  VPX2                       .86663        .353         .47243    .22319    .00329    .04463        3.08301       .000
     VPX1                      2.80330        .052         .47676    .22730    .00411    .04065
     VPX3                      1.63811        .201         .48150    .23184    .00455    .06025
     IPX1                       .35096        .554         .48375    .23401    .00217    .03334
     IPX2                       .02256        .861         .48399    .23425    .00023    .01867
     IPX3                       .15557        .693         .48435    .23460    .00035    .06461
 11  PMX1                      3.22533        .073         .48542    .23563    .00103    .02871        3.04356       0
     PMX2                       .06662        .796         .48890    .23903    .00340    .02525
     PMX3                      4.66455        .031         .49935    .24936    .01033    .06961
 12  VIMX1                     1.22706        .269         .49935    .24936    .00000    .02801        3.01722       .000
     VIMX2                      .37900        .539         .50738    .25744    .00808    .01927
     VIMX3                     3.11933        .078         .51407    .26427    .00683    .05039
 13  VIPX1                     3.16764        .076         .51906    .26942    .00515    .03922        2.88250       0
     VIPX2                      .04393        .834         .51989    .27029    .00086    .03673
     VIPX3                      .45340        .501         .52084    .27129    .00099    .06335
 14  VPMX2                     1.81510        .179         .52105    .27149    .00021    .03992        2.63884       0
     VPMX1                     2.25850        .134         .52813    .27892    .00743    .02841
     VPMX3                      .18567        .667         .52926    .28012    .00120    .06119
     IPMX2                      .44227        .506         .53054    .28148    .00136    .01319
     IPMX1                      .66854        .414         .53106    .28202    .00055    .01964
     IPMX3                      .61459        .434         .53233    .28337    .00135    .06767
 15  VIPMX1                     .67695        .411         .53291    .28399    .00062    .02326        2.45202       .000
     VIPMX2                     .11056        .740         .53293    .28402    .00002    .02924
     VIPMX3                     .75836        .384         .53450    .28569    .00167    .05978
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DEPENDENT VARIABLE..   ACSRSUB


                                          S U M M A R Y   T A B L E

STEP      VARIABLE                   F TO       SIGNIFICANCE   MULTIPLE R   R SQUARE   R SQUARE   SIMPLE R          OVERALL F   SIGNIFICANCE
     ENTERED   REMOVED        ENTER OR REMOVE                                          CHANGE

  1  VVCV                          .00188          .965          .01394      .00019     .00019     .01394            .43016        .651
     VVCI                          .78746          .375          .04791      .00230     .00210     .04785
  2  PARSTCT                      8.23127          .004          .15439      .02384     .02154    -.14420           3.03607        .029
  3  PPRT                        60.57855          .000          .40067      .16054     .13670     .39238          17.78551        .000
  4  X2                            .02008          .887          .40216      .16173     .00119    -.02071          10.53977         0
     X1                           1.66624          .198          .40811      .16655     .00482    -.05888
     X3                            .03198          .858          .40820      .16663     .00007    -.04339
  5  VX2                           .16579          .681          .41009      .16818     .00155    -.00020           6.04314         0
     VX1                           .77945          .378          .41623      .17324     .00507    -.02113
     VX3                           .09338          .760          .41630      .17330     .00006    -.02439
     IX1                           .54360          .332          .41657      .17353     .00023    -.05179
     IX2                          1.06432          .303          .42116      .17738     .00385    -.02544
     IX3                           .23715          .627          .42180      .17792     .00054    -.04620
  6  PX1                           .10255          .749          .42263      .17861     .00070    -.07516           5.07233        .000
     PX3                          1.30742          .254          .42818      .18334     .00473    -.05896
     PX2                           .27587          .600          .42891      .18396     .00063    -.03645
  7  PX2                           .02311          .879          .42916      .18418     .00021    -.00342           4.35941         0
     PX1                          1.24655          .265          .43061      .18543     .00125    -.05446
     PX3                          1.27277          .260          .43396      .18832     .00289    -.04197
  8  VIX1                          .00300          .956          .43660      .19062     .00230    -.01077           3.94135        .000
     VIX2                         1.03660          .309          .44227      .19560     .00499     .00179
     VIX3                          .50538          .478          .44357      .19675     .00115    -.02063
  9  VPX1                          .00699          .933          .44443      .19751     .00076    -.03815           3.30338        .000
     VPX2                          .28043          .597          .44694      .19975     .00224    -.01156
     VPX3                         1.01597          .314          .44981      .20233     .00257    -.03977
     IPX1                         3.14955          .077          .45746      .20927     .00694    -.07418
     IPX2                          .00002          .996          .45755      .20935     .00007    -.04247
     IPX3                          .27822          .598          .45823      .20998     .00063    -.06406
 10  VPX2                          .00012          .991          .45835      .21009     .00011     .01682           2.84083        .000
     VPX1                         2.02576          .156          .46190      .21336     .00327    -.02836
     VPX3                         1.36288          .244          .46729      .21836     .00500    -.01814
     IPX1                          .32886          .567          .46761      .21866     .00030    -.04976
     IPX2                          .15501          .694          .46763      .21868     .00002    -.00615
     IPX3                          .67876          .411          .46928      .22023     .00155    -.03919
 11  PPX1                          .81790          .366          .46934      .22028     .00005    -.07010           2.81223         0
     PPX2                          .31465          .575          .46992      .22082     .00054    -.01868
     PPX3                         6.21632          .013          .48462      .23485     .01403    -.05236
 12  VIMX1                         .08231          .774          .48533      .23555     .00069    -.03218           2.60530        .000
     VIMX2                         .06586          .792          .48539      .23560     .00005    -.01112
     VIMX3                         .45513          .481          .48655      .23673     .00113    -.03860
 13  VIPX1                        5.25619          .022          .49910      .24910     .01237    -.02193           2.58465        .000
     VIPX2                         .11930          .730          .49993      .24993     .00083     .01933
     VIPX3                         .13455          .714          .50024      .25024     .00030    -.01189
 14  VPMX2                        1.00063          .318          .50137      .25137     .00113     .00580           2.44212        .000
     VPMX1                        3.55458          .046          .50681      .25685     .00548    -.04611
     VPMX3                         .04090          .840          .50718      .25724     .00038    -.02970
     IPMX2                         .02004          .888          .50836      .25843     .00119    -.02198
     IPMX1                        3.37503          .067          .51758      .26789     .00946    -.07037
     IPMX3                         .00658          .935          .51760      .26791     .00001    -.05170
 15  VIPMX1                       1.24054          .266          .51785      .26817     .00026    -.04282           2.42350        .000
     VIPMX2                       1.58088          .210          .51790      .26822     .00005     .00725
     VIPMX3                       5.31788          .022          .52918      .28004     .01182    -.02553
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DEPENDENT VARIABLE..     TRANST

                                              S U M M A R Y   T A B L E

STEP      VARIABLE                    F TO       SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R        OVERALL F   SIGNIFICANCE
     ENTERED   REMOVED        ENTER OR REMOVE                                         CHANGE

  1  VVCV                         1.15743           .283         .04270     .00182    .00192   -.04270          .76070        .468
     VVCI                          .73097           .393         .05924     .00351    .00169    .02898
  2  MARSTGT                      21.25885           .000         .22439     .05035    .04684   -.20213         7.61720        .000
  3  PPRT                         72.97811           .000         .43375     .18814 [illegible]   .40175        24.91150        .000
  4  X3                            .02891           .865         .43439     .18861 [illegible]  -.02849        14.40626          0
     X2                            .93385           .334         .43700     .19097    .00227   -.04837
     X1                            .04306           .836         .43709     .19105    .00009   -.03899
  5  VX2                          1.52269           .218         .43979     .19341    .00236   -.02503         8.04211          0
     VX3                           .95248           .330         .44011     .19370    .00029   -.00994
     VX1                          2.41705           .121         .44394     .19708    .00338   -.04497
     IX3                           .36152           .548         .44426     .19736    .00028   -.02914
     IX1                           .82291           .365         .44579     .19873    .00136   -.04125
     IX2                           .10585           .745         .44602     .19893    .00020   -.04696
  6  MX1                           .88525           .347         .44735     .20013    .00119   -.05349         6.59109        .000
     MX3                           .69230           .406         .44874     .20137    .00124   -.01939
     MX2                           .04982           .823         .44885     .20146    .00010   -.04899
  7  PX2                          1.36353           .244         .45246     .20472    .00325   -.05933         5.68561          0
     PX1                           .84484           .359         .45355     .20571    .00099   -.03739
     PX3                           .43451           .510         .45447     .20654    .00083   -.05672
  8  VIX1                          .00324           .955         .45575     .20771    .00116   -.04652         5.02413        .000
     VIX3                         1.76123           .185         .45992     .21153    .00382   -.01317
     VIX2                          .00007           .993         .45992     .21153    .00000   -.02537
  9  VMX1                          .00000          1.000         .45997     .21158    .00005   -.06340         3.96247        .000
     VMX2                          .15892           .690         .45998     .21158    .00000   -.03057
     VMX3                          .48760           .485         .46086     .21239    .00082   -.00504
     IMX3                          .20825           .648         .46099     .21251    .00011   -.02079
     IMX1                          .36135           .548         .46109     .21260    .00009   -.05672
     IMX2                         1.04563           .307         .46327     .21462    .00202   -.04722
 10  VPX2                         2.05242           .153         .46691     .21801    .00339   -.02909         3.36981        .000
     VPX1                         1.67446           .196         .47002     .22092    .00291   -.04792
     VPX3                          .08799           .767         .47003     .22093    .00001   -.03720
     IPX1                          .43185           .511         .47045     .22132    .00039   -.04181
     IPX3                          .68464           .408         .47178     .22258    .00125   -.05862
     IPX2                          .04111           .839         .47187     .22266    .00008   -.05684
 11  PMX1                         1.36210           .244         .47340     .22411    .00145   -.04432         3.12552          0
     PMX2                          .39040           .532         .47472     .22536    .00125   -.06085
     PMX3                          .11338           .737         .47496     .22558    .00022   -.04718
 12  VIMX3                        1.55955           .212         .47539     .22600    .00041   -.00853         3.07556        .000
     VIMX1                        2.05651           .152         .48474     .23497    .00898   -.06474
     VIMX2                        1.53556           .216         .48780     .23794    .00297   -.02983
 13  VIPX1                         .47940           .489         .48826     .23840    .00046   -.04972         2.98604          0
     VIPX2                        4.13002           .043         .49399     .24402    .00562   -.02782
     VIPX3                        1.65413           .199         .49720     .24721    .00318   -.03973
 14  VPMX2                        1.58081           .209         .50604     .25609    .00887   -.03698         2.94281          0
     VPMX1                         .40693           .524         .51038     .26049    .00441   -.06174
     VPMX3                        1.76086           .185         .51455     .26477    .00429   -.03509
     IPMX2                        4.00444           .046         .51982     .27022    .00545   -.05695
     IPMX1                         .50192           .479         .52156     .27203    .00181   -.04957
     IPMX3                         .24105           .624         .52200     .27248    .00046   -.04936
 15  VIPMX2                        .16018           .689         .52232     .27281    .00033   -.03419         2.76864        .000
     VIPMX1                        .36162           .548         .52251     .27302    .00021   -.06398
     VIPMX3                        .36833           .544         .52318     .27372    .00070   -.03783
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DEPENDENT VARIABLE..   NTRANST


                                              S U M M A R Y   T A B L E

STEP      VARIABLE                 F TO      SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R         OVERALL F  SIGNIFICANCE
     ENTERED   REMOVED      ENTER OR REMOVE                                       CHANGE

  1  VVQV                          .12926       .719        .00799     .00006    .00006   -.00799           .31870       .727
     VVQI                          .60974       .435        .03834     .00147    .00141    .03423
  2  MARSTOT                     19.91455       .000        .21324     .04547    .04400   -.20187          6.85993       .000
  3  PPRT                        77.52274       0           .43702     .19099    .14551    .41046         25.43699       .000
  4  X2                           1.48283       .224        .44667     .19952    .00853   -.09046         15.38656       .000
     X1                            .46883       .494        .44817     .20086    .00134   -.08931
     X3                            .10503       .746        .44839     .20105    .00020   -.07749
  5  VA2                           .09787       .341        .44849     .20114    .00008   -.08492          8.85569       .000
     VA3                           .01695       .894        .44953     .20208    .00094   -.08050
     VA1                          3.95398       .047        .45459     .20665    .00458   -.11019
     IA3                           .72977       .393        .45631     .20822    .00156   -.08395
     IA1                          2.46011       .118        .45902     .21070    .00248   -.09191
     IA2                          1.93061       .163        .46296     .21433    .00363   -.09782
  6  MA1                          1.09243       .297        .46299     .21435    .00002   -.09036          7.51633       .000
     MA3                           .32368       .570        .46633     .21747    .00311   -.07936
     MA2                          2.99085       .084        .47224     .22301    .00555   -.10307
  7  PA2                           .01413       .905        .47445     .22510    .00209   -.06316          6.85474       .000
     PA1                          7.42557       .007        .48629     .23648    .01138   -.05134
     PA3                          1.21164       .272        .48856     .23869    .00222   -.08335
  8  VIX1                         1.55545       .213        .49142     .24149    .00279   -.11359          5.99474       .000
     VIX3                          .00193       .969        .49146     .24153    .00004   -.08452
     VIX2                          .27848       .598        .49198     .24204    .00051   -.08969
  9  VMX1                          .56021       .455        .49242     .24248    .00044   -.11558          4.73057       .000
     VMX2                          .15450       .694        .49315     .24319    .00072   -.10308
     VMX3                          .04655       .829        .49320     .24325    .00005   -.08762
     IMX3                          .18283       .669        .49327     .24331    .00006   -.08559
     IMX1                          .28913       .591        .49468     .24471    .00140   -.09471
     IMX2                          .44538       .505        .49552     .24554    .00083   -.11218
 10  VPX2                          .07180       .789        .49575     .24577    .00024   -.05290          3.92139       .000
     VPX1                          .13714       .711        .49721     .24722    .00145   -.07830
     VPX3                          .02237       .881        .49724     .24725    .00003   -.08413
     IPX1                          .72876       .394        .49777     .24778    .00053   -.05869
     IPX3                          .00000       .999        .49793     .24793    .00015   -.08740
     IPX2                          .85042       .357        .49952     .24952    .00159   -.06658
 11  PMX1                          .05738       .811        .49958     .24958    .00006   -.05442          3.62724       .000
     PMX2                         1.31839       .252        .50210     .25211    .00252   -.08186
     PMX3                          .03455       .853        .50217     .25217    .00006   -.08643
 12  VIMX3                         .67207       .413        .50358     .25359    .00142   -.09246          3.38417       .000
     VIMX1                         .81333       .368        .50455     .25457    .00098   -.12081
     VIMX2                         .35088       .554        .50521     .25523    .00066   -.11047
 13  VIPX1                         .33840       .561        .50541     .25544    .00020   -.08461          3.27740       .000
     VIPX2                         .30799       .579        .50545     .25548    .00004   -.05382
     VIPX3                        4.77491       .020        .51424     .26444    .00896   -.08520
 14  VPMX2                         .41358       .521        .51618     .26644    .00200   -.07694          2.99926       .000
     VPMX1                         .00617       .937        .51731     .26761    .00117   -.08673
     VPMX3                         .85860       .355        .51913     .26949    .00188   -.09437
     IPMX2                        1.51529       .219        .52016     .27057    .00108   -.08644
     IPMX1                        2.53925       .112        .52505     .27568    .00511   -.05382
     IPMX3                         .03651       .849        .52512     .27575    .00007   -.09054
 15  VIPMX2                        .00002       .996        .52514     .27577    .00002   -.08002          2.80545       .000
     VIPMX1                        .01766       .894        .52520     .27583    .00006   -.09561
     VIPMX3                        .00146       .970        .52520     .27583    .00000   -.09552
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DEPENDENT VARIABLE..   CECHILO

                                                    S U M M A R Y   T A B L E

STEP        VARIABLE                     F TO       SIGNIFICANCE   MULTIPLE R   R SQUARE   R SQUARE   SIMPLE R        OVERALL F   SIGNIFICANCE
     ENTERED   REMOVED           ENTER OR REMOVE                                           CHANGE

  1  VVQV                              .04533          .832         .01677      .00028     .00028     .01677         2.24620        .107
     VVQI                             4.37363          .037         .10312      .01063     .01035     .10260
  2  MAPSTOT                          9.62448          .002         .18153      .03295     .02232    -.14095         4.73652        .003
  3  PPRT                            34.57895          .000         .32736      .10717     .07421     .30401        12.48319        .000
  4  X2                               1.47397          .225         .34542      .11932     .01215    -.10845         8.32796         0
     X1                                .00038          .984         .34612      .11980     .00048    -.07957
     X3                               1.83535          .176         .35170      .12369     .00389    -.11857
  5  VX2                              2.77086          .097         .35396      .12529     .00160    -.08522         4.85779         0
     VX3                               .57695          .448         .36098      .13031     .00502    -.12309
     VX1                              1.56797          .211         .36585      .13385     .00354    -.09208
     IX3                               .59064          .443         .36761      .13514     .00129    -.12406
     IX1                               .00001          .998         .36763      .13515     .00002    -.08641
     IX2                               .05780          .810         .36780      .13529     .00012    -.10492
  6  MX1                              1.90625          .168         .36820      .13557     .00029    -.07256         4.23629        .000
     MX3                               .35960          .528         .37290      .13905     .00349    -.11540
     MX2                              2.17783          .141         .37904      .14367     .00462    -.11719
  7  PX2                               .40372          .526         .37988      .14431     .00064    -.08851         3.85525         0
     PX1                              3.80754          .052         .39292      .15439     .01008    -.05194
     PX3                               .03118          .860         .39301      .15445     .00007    -.11063
  8  VIX1                              .17878          .673         .39552      .15644     .00199    -.09974         3.48030        .000
     VIX3                              .67840          .411         .39580      .15666     .00022    -.12696
     VIX2                             2.22187          .137         .40167      .16134     .00468    -.09727
  9  VMX1                              .25651          .613         .40195      .16156     .00022    -.09126         3.12040        .000
     VMX2                             1.10959          .293         .40403      .16324     .00168    -.09509
     VMX3                              .07913          .779         .40403      .16324     .00000    -.12431
     IMX3                             3.16631          .076         .40409      .16329     .00004    -.12106
     IMX1                             4.61946          .032         .42346      .17932     .01603    -.08429
     IMX2                             1.41104          .236         .42692      .18226     .00294    -.11731
 10  VPX2                              .05990          .807         .42699      .18232     .00005    -.06482         2.64718        .000
     VPX1                             1.62636          .203         .43016      .18504     .00272    -.07030
     VPX3                              .77093          .380         .43129      .18601     .00098    -.11186
     IPX1                              .02853          .866         .43145      .18615     .00014    -.06163
     IPX3                             1.37990          .241         .43471      .18897     .00282    -.11653
     IPX2                              .05373          .817         .43484      .18908     .00011    -.08855
 11  PMX1                              .04792          .827         .43487      .18911     .00003    -.04702         2.44284        .000
     PMX2                              .45807          .481         .43534      .18952     .00040    -.09894
     PMX3                              .67032          .413         .43696      .19093     .00142    -.11166
 12  VIMX1                             .08116          .776         .43789      .19175     .00082    -.10370         2.31518        .000
     VIMX3                            1.74474          .187         .44016      .19374     .00199    -.12879
     VIMX2                            1.04329          .308         .44266      .19595     .00221    -.10013
 13  VIPX1                             .11404          .736         .44283      .19610     .00015    -.07905         2.15251        .000
     VIPX2                             .44815          .504         .44364      .19681     .00072    -.06805
     VIPX3                             .14188          .707         .44398      .19712     .00030    -.11659
 14  VPMX1                             .46680          .495         .44831      .20099     .00387    -.07292         2.11785        .000
     VPMX2                             .24634          .620         .44833      .20100     .00001    -.07519
     VPMX3                             .10554          .745         .44936      .20192     .00092    -.11859
     IPMX2                            6.00181          .015         .45573      .20769     .00577    -.10039
     IPMX1                             .35398          .552         .46044      .21201     .00432    -.06102
     IPMX3                            3.11925          .078         .46752      .21858     .00657    -.11782
 15  VIPMX2                            .09913          .753         .46831      .21932     .00074    -.08021         1.99247        .000
     VIPMX1                            .03562          .850         .46832      .21932     .00000    -.08631
     VIPMX3                            .17521          .676         .46871      .21969     .00037    -.12399
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DEPENDENT VARIABLE..     ACECHILD

                                    S U M M A R Y   T A B L E

STEP      VARIABLE                    F TO      SIGNIFICANCE  MULTIPLE R  R SQUARE  R SQUARE  SIMPLE R       OVERALL F  SIGNIFICANCE
     ENTERED   REMOVED          ENTER OR REMOVE                                      CHANGE

  1   VVCV                         2.55864          .110        .04834     .00234    .00234   -.04834       3.37877       .035
      VV0I                         5.74856          .017        .12510     .01565    .01331    .09862
  2   MAPSTOT                     16.28378          .000        .22816     .05206    .03641   -.16961       7.76144       .000
  3   PPRT                        27.75425             0        .33230     .11042    .05837    .281[illegible]  13.12695    .000
  4   X2                           1.13414          .288        .33401     .11157    .00114   -.03[illegible]  7.67128     .000
      X1                            .00415          .949        .33446     .11187    .00030   -.00157
      X3                            .70850          .400        .33669     .11336    .00150    .01547
  5   VX2                           .02644          .871        .33684     .11346    .00010   -.02988       4.10417       .000
      VX3                           .00103          .974        .33686     .11348    .00002    .01733
      VX1                           .01433          .905        .33700     .11357    .00009    .00281
      IX3                           .01252          .911        .33724     .11373    .00016    .01356
      IX1                           .03652          .849        .33724     .11373    .00000   -.00516
      IX2                           .20089          .654        .33788     .11416    .00043   -.03477
  6   MX1                          1.13864          .287        .34338     .11791    .00375    .00930       3.43954       .000
      MX3                           .07583          .783        .34354     .11802    .00011    .02979
      MX2                           .03230          .857        .34364     .11809    .00007   -.01862
  7   PX2                           .43440          .510        .34371     .11814    .00005   -.02960       3.02051       .000
      PX1                          1.83491          .176        .35106     .12324    .00511    .00940
      PX3                           .03459          .853        .35116     .12332    .00007    .00957
  8   VIX1                          .00005          .994        .35290     .12454    .00122   -.00405       2.71116       .000
      VIX3                          .02368          .878        .35320     .12475    .00021    .01268
      VIX2                         1.68055          .196        .35828     .12837    .00362   -.03965
  9   VMX3                         1.20931          .272        .36093     .13027    .00190    .02360       2.34985       .000
      VMX2                          .00872          .926        .36098     .13031    .00004   -.02479
      VMX1                          .65406          .419        .36321     .13192    .00161    .01026
      IMX3                          .14855          .700        .36483     .13310    .00118    .02559
      IMX1                          .24964          .618        .36911     .13624    .00314    .00227
      IMX2                         2.47179          .117        .37624     .14156    .00532   -.02777
 10   VPX2                          .06921          .793        .37860     .14333    .00178   -.03262       2.28148       .000
      VPX1                         1.92873          .166        .38700     .14977    .00643    .00330
      VPX3                          .63264          .427        .39191     .15359    .00382    .01485
      IPX1                         3.[illegible]8766    .075    .39971     .15977    .00618   -.00225
      IPX3                         2.27797          .132        .40450     .16362    .00385    .00884
      IPX2                          .57679          .448        .40601     .16484    .00123   -.03837
 11   PMX1                          .41675          .519        .40935     .16757    .00272    .01738       2.14036       .000
      PMX2                          .48700          .486        .41084     .16879    .00122   -.02354
      PMX3                          .00007          .993        .41084     .16879    .00000    .02074
 12   VIMX3                         .08472          .771        .41111     .16901    .00023    .01700       1.99077       .001
      VIMX1                         .42050          .517        .41292     .17051    .00149    .00093
      VIMX2                         .06707          .796        .41310     .17065    .00014   -.03816
 13   VIPX1                         .09310          .760        .41365     .17111    .00046   -.00840       1.89665       .001
      VIPX2                        1.50488          .221        .41610     .17314    .00203   -.04467
      VIPX3                         .94945          .330        .41855     .17518    .00204    .01183
 14   VPMX1                        4.00327          .046        .42896     .18401    .00883    .00766       1.83261       .001
      VPMX2                         .01406          .906        .43018     .18506    .00105   -.03132
      VPMX3                         .81901          .366        .43172     .18638    .00132    .01847
      IPMX2                        2.03591          .154        .43487     .18911    .00273   -.03449
      IPMX1                        1.16195          .282        .43813     .19195    .00284    .00297
      IPMX3                         .00194          .965        .43813     .19196    .00000    .01840
 15   VIPMX2                        .07277          .787        .43833     .19213    .00018   -.04575       1.77345       .001
      VIPMX1                       2.05662          .152        .44023     .19380    .00167   -.00701
      VIPMX3                       1.66986          .197        .44427     .19738    .00357    .01379
```

APPENDIX I

Schedule Forms

Name____________________

School____________________

Chem. Teacher____________________

DIRECTIONS: Place an X in the space below designating when you have time for a feedback session on problem solving. This should be done during your study hall, free period, and or after school. Please indicate as many of these times as you have available, although you will just be interviewed one time every few months.

SCHEDULE:

PERIOD	X
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
After School	

FEEDBACK: We would like to find out how you go about solving problems. Each student who participates in the feedback sessions will be paid 3.00 per session. These sessions in no way will be used to evaluate you. The discussion in the feedback session will be confidential. Your teacher will not be informed of what you do in these sessions. We would appreciate your help.

Please return this form to your teacher.

Name________________________

School________________________

Chem. Teacher________________________

DIRECTIONS: Place an X in the space below designating when you have time for a feedback session on problem solving. This should be done during your study hall, free period, and or after school. Please indicate as many of these times as you have available, although you will just be interviewed one time every few months.

SCHEDULE:

PERIOD	X
1.	
2.	
3.	
4.	
Home Room Activities	
5.	
6.	
After School	

FEEDBACK: We would like to find out how you go about solving problems. These sessions in no way will be used to evaluate you. The discussion in the the feedback session will be confidential. Your teacher will not be informed of what you do in these sessions. We would appreciate your help.

Please return this form to your instructor.

APPENDIX J

Protocol for Conducting Interviews

INTERVIEWING PROTOCOL

Equipment Check

EQUIPMENT:

TAPE RECORDER (WITH MICROPHONE)

EXTENSION CORD

TAPE (BLANK)

WHIMBEY TAPE

TWO CHAIRS

TABLE

PAPER

PENCILS

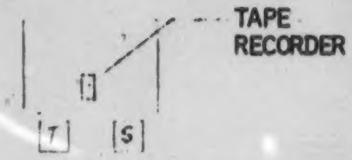
RESPONSE SHEET

OPERATION CHECKS:

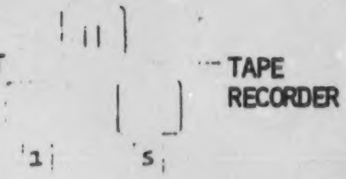
1. TAPE RECORDER WORKING?
2. TAPE REWOUND?
3. VOLUME CONTROLS SET?

SET-UP:

A. WITH TABLE



B. WITH STUDENT CHAIRS



I | INTERVIEWER

S | STUDENT

CARD 1

(START TAPE.) INTRODUCTION: MY NAME IS MR./MS.________FROM INDIANA UNIVERSITY, I AM PART OF A GROUP OF SCIENCE EDUCATORS THAT IS TRYING TO HELP STUDENTS LEARN TO SOLVE CHEMISTRY PROBLEMS. IF YOU HAVE NO OBJECTIONS, I WILL TAPE OUR CONVERSATION. YOU WILL NOT BE REQUIRED TO LISTEN TO THE TAPE. THIS FEEDBACK SESSION IS TO SEE HOW YOU GO ABOUT SOLVING CHEMISTRY PROBLEMS. THIS IS NOT A TEST AND IS TOTALLY PRIVATE. I WILL NOT BE REPORTING BACK TO YOUR TEACHER ON HOW WELL YOU DO. THEY WILL NOT HEAR THE TAPE.

CARD 2 WHIMBEY TAPE

I AM GOING TO PLAY A TAPE FOR YOU TO SHOW YOU HOW I WOULD LIKE FOR YOU TO SOLVE THE PROBLEMS AND ANSWER QUESTIONS. THE PERSON IN THE TAPE WILL READ THE PROBLEM ALOUD AND ALSO SOLVE IT ALOUD. ALL THOUGHTS CONCERNING THE PROBLEM SHOULD BE SPOKEN ALOUD. THIS WAY, I WILL KNOW WHAT YOU ARE THINKING AND, THEREFORE, BE ABLE TO HELP YOU.

LET'S LISTEN TO SOMEONE THINKING ALOUD. (STOP RECORDER) (PLAY TAPE AND GIVE STUDENT WHIMBEY PROBLEM.)

CARD 3

PROBLEM

IF THE CIRCLE BELOW IS TALLER THAN THE SQUARE AND THE CROSS IS SHORTER THAN THE SQUARE, PUT A "K" IN THE CIRCLE. HOWEVER, IF THIS IS NOT THE CASE, PUT A "T" IN THE SECOND TALLEST FIGURE.

CARD 4

(START RECORDER.) NOW LET'S PRACTICE THIS THINK-ALOUD TECHNIQUE. I WOULD LIKE FOR YOU TO SOLVE THE FOLLOWING PROBLEM ALOUD. FIRST READ IT, THEN SPEAK YOUR THOUGHTS AS YOU SOLVE IT. YOU MAY DO YOUR FIGURING ON A PIECE OF PAPER, BUT TELL ME WHAT YOU ARE THINKING WHILE YOU WRITE. HERE IS THE PROBLEM:

CARD 5

PROBLEM

HARVEY OWES SAM $27.00. SAM OWES FRED $6.00 AND ALBERT $15.30. IF, WITH SAM'S PERMISSION, HARVEY PAYS OFF SAM'S DEBT TO ALBERT, HOW MUCH DOES HARVEY STILL OWE SAM?

CARD 6 QUESTIONS

NOW THAT YOU HAVE THE IDEA, LET'S TRY SOME CHEMISTRY QUESTIONS. REMEMBER, LET ME HEAR YOU THINKING AS YOU ANSWER. (ASK THE QUESTIONS ON THE FOLLOWING CARD.)
(SHOULD GIVE THE STUDENT THE ANSWER IF HE/SHE DOES NOT KNOW)
(PROMPT IN CASE OF SILENCE)

CARD 7

(QUESTIONS)

EACH UNIT HAS A DIFFERENT SET OF QUESTIONS. THEY ARE TO BE ATTACHED TO THIS CARD AS NEEDED.

CARD 8

NOW LET'S TRY SOME PROBLEMS. YOU MAY USE PENCIL, PAPER, AND AN ATOMIC MASS TABLE, IF YOU NEED IT. ON ALL OF THE FOLLOWING PROBLEMS YOU CAN DO YOUR FIGURING ON A SHEET OF PAPER, BUT TELL ME WHAT YOU ARE THINKING WHILE YOU WRITE.

HERE IS THE FIRST PROBLEM. REMEMBER TO READ IT ALOUD, AND THINK ALOUD DURING YOUR PROBLEM SOLVING. I WOULD LIKE TO HEAR ALL YOUR THOUGHTS RELATING TO THE PROBLEM. (WHILE STUDENT IS SOLVING THE PROBLEM, YOU SHOULD BE WRITING ON THE RESPONSE SHEET) (ONLY PROMPT THINK-ALOUD PROCESS--NO ASSISTANCE) (GIVE FIRST PROBLEM, SELECT AT RANDOM) (DIFFERENT PROBLEM SETS ARE USED FOR EACH UNIT)

CARD 9

NOW LET'S TRY ANOTHER PROBLEM. (GIVE SECOND PROBLEM, SELECT AT RANDOM)

NOW LET'S TRY A THIRD PROBLEM. (GIVE A THIRD PROBLEM, SELECT AT RANDOM)

(IF METHOD WAS NOT EVIDENT, I.E. D, F, A, OR P, ASK THE STUDENT WHICH METHOD HE/SHE USED. HAVE THEM SHOW YOU THE METHOD.)

(SHOW ME HOW YOU USED THIS METHOD ON PROBLEM ONE.)

CARD 10

THANK YOU FOR YOUR HELP. DO YOU HAVE ANY COMMENTS ABOUT THIS SESSION?
(STOP TAPE)
IN ORDER FOR US TO PAY YOU FOR THIS SESSION, PLEASE SIGN AND DATE THIS FORM.

APPENDIX K

Teacher Instructions for Interviews

Feedback Session Procedures

Time: Each session will last approximately 45 minutes, and will be conducted where possible during study periods. It may be necessary at times to have sessions after school or during class time.

Where: The session will take place in a separate room away from the chemistry classroom.

Supportive Materials: Audio tape and recorder will be needed to record the interview. The student will be provided with a calculator, periodic chart, unlined paper, and a pencil.

Selection of students: From the tests administered at the beginning of the school year, the students will be classified according to the diagram below:

Proportional Reasoning

	Low	High
Visual		
Verbal		

Sixteen students from each of the four groups will participate in a session following each of the four instructional units. Selection of the students from each group will be made on the basis of their success or failure on the immediate post test and on the instructional strategy used. Eight students who were able to solve the problems and eight who were not will be used. In order to encourage participation, $3.00 will be paid the student for each session.

Initial Instruction to the student: Prior to the feedback session the students will be given the following instructions:

1. The student will be told that he/she will be solving problems like he/she had done in class.
2. The student will be told that the session will be private. The concept of complete privacy should be emphasized. The student is to be insured that nothing said, nor the results of any problems, will be repeated to the teacher or classmates of the student.

3. The student will be informed that the interviewer will be primarily interested in how the problems are solved.
4. Each student will be asked if he/she objects to being audiorecorded, and will be told that they will not be required to listen to the tape being replayed.

The Session: The students will use a Think-Aloud Technique. This technique will be divided into three sections as follows:

1. Think-Aloud Warm-up
   - a) The student listens to a short tape of a person solving a problem aloud.
   - b) The student is taped while solving a think-aloud problem from Whimbey.
   - c) The student is informed of the importance of thinking aloud while solving the problems during the session.
2. Questions Section: Chemistry content questions will be asked to establish background and set the tone for the session. A typical question might be as follows:

   In the molecule H_2SO_4, how many atoms of each element are present?

   The interviewer will respond to the question when appropriate.
3. Problem Section: Two problems will be presented to the student (from a pool of three items of each type) to be solved by thinking aloud. The interviewer will prompt the student with a general question such as, "What are you thinking now?" only when the think aloud process breaks down. No hints to the problem solving will be given. The interviewer will take notes on paper while the student is thinking aloud. It has been shown that this will stimulate the think-aloud process. Examples of the problems are as follows:
   - a. One step - How many moles of H_2SO_4 are present in 90 grams of H_2SO_4?
   - b. Two step - What is the mass of 80 liters of neon gas?

Post Session: The tapes will be coded according to the attached form.

APPENDIX L

Interview Questions, Problems, Answers

Moles. 569
Gas Laws 571
Stoichiometry. 573
Molarity 577

Moles Questions

Q1. The formula for calcium hydroxide is $Ca(OH)_2$. (SHOW STUDENT CARD). How many atoms of each element are present in a molecule of calcium hydroxide?

Expected Response (E.R.) - 1 calcium, 2 oxygen, 2 hydrogen

Q2. If you had a mole of something, what would that mean to you?

E.R. - A mole represents a certain number of particles, volume, and mass of a substance.

Q3. How many particles are in one mole?

E.R. - 6.02×10^{23} particles

Q4. What volume would one mole of an ideal gas occupy at STP?

E.R. - 22.4 liters

Q5. How would you determine the mass of one mole of iron?

E.R. - Look up the atomic mass in a table of atomic masses.

Q6. How would you determine the mass of one mole of ammonia (NH_3)? (SHOW STUDENT CARD)

E.R. - Look up atomic mass of nitrogen (N), and hydrogen (H) in atomic mass table. Add up one nitrogen (N), and 3 hydrogen (H) to get mass of 1 mole.

Moles Problems

1M How much would 3 moles of carbon dioxide (CO_2) weigh?

1V What would be the volume of 3 moles of carbon dioxide (CO_2) gas at STP?

1Mo How many molecules of carbon dioxide (CO_2) are present in 3 moles of carbon dioxide?

2VM A sample of methane (CH_4) has a volume of 44.8 liters at STP. What would be the mass of this sample?

2MMo A sample of methane (CH_4) has a mass of 32 grams. How many molecules are in this sample?

2MoV A sample of methane (CH_4) contains 12.04×10^{23} molecules. What volume would this gas occupy at STP?

3VA A sample of hydrogen sulfide (H_2S) has a volume of 67.2 liters at STP. How many hydrogen atoms are present in this sample?

3MA A sample of hydrogen sulfide (H_2S) has a mass of 102.3 grams. How many hydrogen atoms are present in this sample?

3VM A sample of hydrogen sulfide (H_2S) has a volume of 67.2 liters at STP. What would be the mass of the hydrogen atoms in this sample?

Moles Answers

1M $12 + 2(16) = 44$ grams/mole $\quad$ 3 moles $CO_2 \times 44$ grams/mole = 132 grams CO_2

1V 3 moles $CO_2 \times 22.4$ liters/mole = 67.2 liters

1Mo 3 moles $CO_2 \times 6.02 \times 10^{23}$ molecules/mole = 18.06×10^{23} molecules

2VM $\dfrac{44.8 \text{ liters}}{22.4 \text{ liters/mole}} = 2 \text{ moles} \times (12 + 4(1)) = 32 \text{ grams}$

2MMo $12 + 4(1) = 16$ grams/mole $\quad \dfrac{32 \text{ grams}}{16 \text{ grams/mole}} =$

2 moles $\times 6.02 \times 10^{23}$ molecules/moles = 12.04×10^{23} molecules

2MoV $\dfrac{12.04 \times 10^{23} \text{ molecules}}{6.02 \times 10^{23} \text{ molecules/mole}} = 2 \text{ moles} \times 22.4 \text{ liters/mole} =$

44.8 liters

3VA $\dfrac{67.2 \text{ liters}}{22.4 \text{ liters/mole}} = 3 \text{ moles } H_2S \times \dfrac{2 \text{ moles H}}{1 \text{ mole } H_2S} =$

6 moles H $\times 6.02 \times 10^{23}$ atoms/mole = 36.12×10^{23} atoms

3MA $2\,(1) + 32.1 = 34.1$ grams/mole $\quad \dfrac{102.3 \text{ grams } H_2S}{34.1 \text{ grams/mole}} =$

3 moles $H_2S \times \dfrac{2 \text{ moles H}}{1 \text{ mole } H_2S} = 6$ moles $H_2S \times 6.02 \times 10^{23}$ atoms/mole =

36.12×10^{23} atoms H

3VM $\dfrac{67.2 \text{ liters } H_2S}{22.4 \text{ liters/mole}} = 3 \text{ moles } H_2S \times \dfrac{2 \text{ moles H}}{1 \text{ mole } H_2S} =$

6 moles H $\times 1.0 \dfrac{\text{grams}}{\text{mole}} = 6.0$ grams H

Gas Laws Questions

Q1. What would happen to the volume of a gas sample if the pressure on the sample was increased and the temperature held constant?

Expected Response (E.R.) - Volume would decrease.

Q2. What would happen to the volume of a gas sample if the temperature on the sample was increased and the pressure held constant?

E.R. - Volume would increase.

Q3. What would happen to the temperature of a gas sample if the pressure on the sample was decreased and the volume held constant?

E.R. - Temperature will decrease.

Q4. What would happen to the pressure of a gas sample if the temperature and the volume were both increased?

E.R. - Can't tell, depends on the percentage for each effect.

Gas Laws Problems

1TP A sample of gas has a pressure of 600 mm Hg at 27°C. What pressure would this sample have at 127°C? Assume no volume change.

1TV A sample of gas has a volume of 600 ml at 27°C. What volume would this gas occupy at 127°C? Assume no pressure change.

1PV A sample of gas has a volume of 500 ml at 700 mm Hg pressure. What volume would this gas occupy at 350 mm Hg pressure? Assume no temperature change.

2TVP A sample of gas has a pressure of 400 mm Hg with a volume of 600 ml and -73°C temperature. What would be the pressure if the volume became 300 ml and the temperature 27°C?

2TPV A sample of gas has a volume of 600 ml at 400 mm Hg pressure and -73°C temperature. What would be the volume if the pressure became 1200 mm Hg and the temperature 27°C?

2 PVT A sample of gas has a temperature of -73°C at 400 mm Hg pressure and 600 ml volume. What would be the Celsius temperature of the sample if the pressure became 1200 mm Hg and the volume 300 ml?

3M-TV What volume would 3 moles of a gas occupy at -136.5°C and 760 mm Hg?

3M+TV What volume would 3 moles of a gas occupy at 273°C and 760 mm Hg?

3MPV What volume would 3 moles of a gas occupy at 0°C and 1520 mm Hg?

Gas Laws Answers

1TP $$600\text{ mmHg}\times\left(\frac{273+127^{\circ}\text{K}}{273+27^{\circ}\text{K}}\right)=\overset{2}{\cancel{600}}\text{ mm Hg}\times\frac{400}{\underset{1}{\cancel{300}}}=800\text{ mm Hg}$$

1TV $$600\text{ ml}\times\left(\frac{273+127^{\circ}\text{K}}{273+27^{\circ}\text{K}}\right)=\overset{2}{\cancel{600}}\text{ ml}\times\frac{400}{\underset{1}{\cancel{300}}}=800\text{ ml}$$

1PV $$500\text{ ml}\times\frac{\overset{2}{\cancel{700}}\text{ mm Hg}}{\cancel{350}\text{ mm Hg}}=1000\text{ ml}$$

2TVP $$400\text{ mm Hg}\times\frac{600\text{ ml}}{300\text{ ml}}\times\left(\frac{273+27^{\circ}\text{K}}{273+-73^{\circ}\text{K}}\right)=400\text{ mm Hg}\times\frac{2}{1}\times\frac{300}{200}=1200\text{ mm Hg}$$

2TPV $$600\text{ ml}\times\frac{400\text{ mm Hg}}{1200\text{ mm Hg}}\times\left(\frac{273+27^{\circ}\text{K}}{273+-73^{\circ}\text{K}}\right)=600\text{ ml}\times\frac{1}{3}\times\frac{300^{\circ}\text{K}}{200^{\circ}\text{K}}=300\text{ ml}$$

2PVT $$273+(-73^{\circ}\text{C})\times\frac{1200\text{ mm Hg}}{400\text{ mm Hg}}\times\frac{300\text{ ml}}{600\text{ ml}}=200^{\circ}\text{K}\times\frac{3}{1}\times\frac{1}{2}=300^{\circ}\text{K}$$

$300^{\circ}\text{K}-273=27^{\circ}\text{C}$

3M-TV $$3\text{ moles}\times\frac{22.4\text{ liters}}{\text{moles}}\times\frac{-136.5+273}{273}=3\times22.4\text{ liters}\times\frac{136.5}{273}=$$

33.6 liters

3M+TV $$3\text{ moles}\times\frac{22.4\text{ liters}}{\text{moles}}\times\frac{273+273}{273^{\circ}\text{K}}=3\times22.4\text{ liters}\times\frac{546}{273}=$$

134.4 liters

3MPV $$3\text{ moles}\times\frac{22.4\text{ liters}}{\text{moles}}\times\frac{760\text{ mm Hg}}{1520\text{ mm Hg}}=33.6\text{ liters}$$

Stoichiometry Questions

Q1. The formula for calcium hydroxide is $Ca(OH)_2$. (Show Student Card) How many atoms of each element are present in a molecule of calcium hydroxide?

Expected Response (E.R.) - 1 calcium, 2 oxygen, 2 hydrogen.

Q2. If you had a mole of something, what would that mean to you?

E.R. - A mole represents a certain number of particles, volume, and mass of a substance.

Q3. How many particles are in one mole?

E.R. - 6.02×10^{23} particles.

Q4. What volume would one mole of an ideal gas occupy at STP?

E.R. - 22.4 liters.

Q5. How would you determine the mass of one mole of iron?

E.R. - Look up the atomic mass in a Table of Atomic Masses.

Q6. How would you determine the mass of one mole of ammonia (NH_3)? (Show Student Card)

E.R. - Look up atomic mass of nitrogen (N), and Hydrogen (H) in Atomic Mass Table. Add up one nitrogen (N), 3 hydrogen (H) to get mass of 1 mole.

Q7. How would you go about balancing the following equation:

$$NaCl_{(aq)} + H_2SO_{4(aq)} \longrightarrow Na_2SO_{4(aq)} + HCl_{(aq)}$$

E.R. - Two H are needed on right to balance two H on left. Two Cl are needed on left to balance two Cl on right. Other elements balance.

Stoichiometry Problems

1 M Propane gas (C_3H_8) burns (reacts with O_2) to form carbon dioxide (CO_2) and water vapor (H_2O) according to the reaction:

$$C_3H_{8(g)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$$

How many moles of CO_2 would be formed from 3 moles of C_3H_8 reacting with sufficient O_2?

Stoichiometry Problems continued:

1 V Propane gas (C_3H_8) burns (reacts with O_2) to form carbon dioxide (CO_2) and water vapor (H_2O) according to the reaction:

$$C_3H_{8(g)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$$

How many liters of CO_2 (measured at STP) would be formed from 67.2 liters of C_3H_8 (measured at STP) reacting with sufficient O_2?

1 P Propane gas (C_3H_8) burns (reacts with O_2) to form carbon dioxide (CO_2) and water vapor (H_2O) according to the reaction:

$$C_3H_{8(g)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$$

How many molecules of CO_2 would be formed from 18.06×10^{23} molecules of C_3H_8 reacting with sufficient O_2?

2 MM Sodium carbonate (Na_2CO_3) reacts with hydrochloric acid (HCl) to form sodium chloride (NaCl), water (H_2O), and carbon dioxide gas (CO_2) according to the reaction:

$$Na_2CO_{3(aq)} + 2\ HCl(aq) \longrightarrow 2\ NaCl(aq) + H_2O(l) + CO_2(g)$$

How many grams of CO_2 would be produced from 146.0 grams of HCl reacting with sufficient Na_2CO_3?

2 MV Sodium carbonate (Na_2CO_3) reacts with hydrochloric acid (HCl) to form sodium chloride (NaCl), water (H_2O), and carbon dioxide (CO_2) according to the reaction:

$$Na_2CO_3(aq) + 2\ HCl(aq) \longrightarrow 2\ NaCl(aq) + H_2O(l) + CO_2(g)$$

How many liters of CO_2 (measured at STP) would be produced from 146.0 grams of HCl reacting with sufficient Na_2CO_3?

2 MP Sodium carbonate (Na_2CO_3) reacts with hydrochloric acid (HCl) to form sodium chloride (NaCl), water (H_2O), and carbon dioxide gas (CO_2) according to the reaction:

$$Na_2CO_3(aq) + 2\ HCl\ (aq) \longrightarrow 2\ NaCl(aq) + H_2O(l) + CO_2(g)$$

How many molecules of CO_2 would be produced from 146.0 grams of HCl reacting with sufficient Na_2CO_3?

3 HH Silver nitrate ($AgNO_3$) reacts with hydrogen sulfide gas (H_2S) to form silver sulfide (Ag_2S) and nitric acid (HNO_3) according to the reaction:

$$2AgNO_3(aq) + H_2S(g) \longrightarrow Ag_2S(s) + 2\ HNO_3(aq)$$

How many grams of HNO_3 would be formed from combining 255 grams $AgNO_3$ with 17 grams H_2S?

Stoichiometry Problems continued:

3 SS 1 Silver nitrate ($AgNO3$) reacts with hydrogen sulfide gas (H_2S) to form silver sulfide (Ag_2S) and nitric acid (HNO_3) according to the reaction:

$$2\ AgNO_3(aq) + H_2S(g) \longrightarrow Ag_2S(s) + 2\ HNO_3(aq)$$

How many grams of Ag_2S would be formed from combining 170 grams of $AgNO_3$ and 170 grams H_2S?

3 SS 2 Silver nitrate ($AgNO_3$) reacts with hydrogen sulfide gas (H_2S) to form silver sulfide (Ag_2S) and nitric acid (HNO_3) according to the reaction:

$$2\ AgNO_3(aq) + H_2S(g) \longrightarrow Ag_2S(s) + 2\ HNO_3(aq)$$

How many grams of Ag_2S would be formed from combining 340 grams of $AgNO_3$ and 51 grams H_2S?

Stoichiometry Answers

1 M $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4\ H_2O$ 3 moles C H $\times \frac{3 \text{ moles } CO_2}{1 \text{ mole } C_3H_8}$ = 9 moles CO_2

1 P $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$ 18.06×10^{23} molecules $C_3H_8 \times \frac{3 \text{ moles } CO_2}{1 \text{ molecule } C_3H_8}$ =

54.18×10^{23} molecules CO_2

1 V $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$ 67.2 liters $C_3H_8 \times \frac{3 \text{ liters } CO_2}{1 \text{ liter } C_3H_8}$ = 201.6 liters CO_2

2 MM Equation balanced. $\frac{146.0 \text{ grams HCl}}{36.5 \text{ grams/mole}}$ = 4.0 moles HCl $\times \frac{1 \text{ mole } CO_2}{2 \text{ moles HCl}}$ =

2.0 moles CO_2 2.0 moles $CO_2 \times 44\ \frac{\text{grams}}{\text{mole}}$ = 88.0 grams CO_2

2 MV Equation balanced. $\frac{146.0 \text{ grams HCl}}{36.5 \text{ grams/mole}}$ = 4.0 moles HCl $\times \frac{1 \text{ mole } CO_2}{2 \text{ mole HCl}}$ =

2.0 moles $CO_2 \times$ 22.[illegible] $\frac{\text{liters}}{\text{mole}}$ = 44.8 liters CO_2

2 MP Equation balanced. $\frac{146.0 \text{ grams HCl}}{36.5 \text{ grams/mole}}$ = 4.0 moles HCl $\times \frac{1 \text{ mole } CO_2}{2 \text{ moles HCl}}$ =

2.0 moles $CO_2 \times 6.02 \times 10^{23}\ \frac{\text{molecules}}{\text{mole}}$ = 12.04×10^{23} molecules CO_2

3 HH Equation balanced. $\frac{255 \text{ grams } AGNO_3}{170 \text{ grams/mole}}$ = 1.5 moles $AgNO_3$

$\frac{17 \text{ grams } H_2S}{34 \text{ grams/mole}}$ = 0.5 mole H_2S H_2S is limiting reagent

0.5 mole $H_2S \times \frac{2 \text{ mole } HNO_3}{1 \text{ mole } H_2S}$ = 1.0 mole $HNO_3 \times 63\ \frac{\text{grams}}{\text{mole}}$ = 63 grams HNO_3

3 SS 1 $\frac{170 \text{ grams } AgNO_3}{170 \text{ grams/mole}}$ = 1.0 mole $AgNO_3$ $\frac{170 \text{ grams } H_2S}{34 \text{ grams/mole}}$ = 5.0 mole H_2S

$AgNO_3$ limiting reagent 1.0 mole $AgNO_3 \times \frac{1 \text{ mole } Ag_2S}{2 \text{ moles } AgNO_3}$ = 0.5 mole Ag_2S

0.5 mole $Ag_2S \times 248\ \frac{\text{grams}}{\text{mole}}$ = 124 grams Ag_2S

3 SS 2 $\frac{340 \text{ grams } AgNO_3}{170 \text{ grams/mole}}$ = 2.0 moles $AgNO_3$ $\frac{51 \text{ grams } H_2S}{34 \text{ grams/mole}}$ = 1.5 moles H_2S

$AgNO_3$ limiting reagent 2.0 moles $AgNO_3 \times \frac{1 \text{ mole } Ag_2S}{2 \text{ moles } AgNO_3}$ = 1.0 mole Ag_2S

1.0 mole $Ag_2S \times 248\ \frac{\text{grams}}{\text{mole}}$ = 248 grams Ag_2S

Molarity Questions

Q1. How would you determine the mass of one mole of iron?

Expected Response (E.R.) - Look up the atomic mass in a Table of Atomic Masses.

Q2. How would you determine the mass of one mole of ammonia (NH_3)? (Show Student Card)

E.R. - Look up atomic mass of N, and H in atomic mass table. Add up one N and 3 H to get mass of one mole.

Q3. How many milliliters are equal to 2.5 liters?

E.R. - 2500 ml

Q4. Define molarity in your own words.

E.R. - The moles of material dissolved per liter of solution. Moles/liter (accepted).

Q5. How would you make up one liter of a two molar sodium chloride solution?

E.R. - Determine molecular mass of NaCl, weigh out the equivalent of 2 moles (2 molecular masses) of NaCl. Dissolve material in enough water to make one liter of solution.

Molarity Problems

1 M1 How many ml of a 0.5 M potassium fluoride (KF) solution would contain 116.2 grams of KF?

1G How many grams of potassium fluoride (KF) are present in 4000 ml of a 0.5 M solution of KF?

1 Mo What would be the molarity of a solution made by dissolving 116.2 grams of potassium fluoride (KF) in enough water to form 4000 ml of solution?

2 MoD What would be the molarity of a solution made by adding 500 ml of water to 1500 ml of a 3.0 M LiCl solution?

2 MoC What would be the molarity of a solution made by boiling off 500 ml of water from 2000 ml of a 2.25 M LiCl solution?

2 MoV How many ml of water must be added to 1500 ml of a 3.0 M LiCl solution in order for the molarity to become 2.25 M?

3 WA Sodium carbonate (Na_2CO_3) reacts with phosphoric acid (H_3PO_4) to produce sodium phosphate (Na_3PO_4), water (H_2O), and carbon dioxide gas (CO_2) according to the balanced reaction:

$$3\ Na_2CO_{3(s)} + 2\ H_3PO_{4(aq)} \longrightarrow 2\ Na_3PO_{4(aq)} + 3\ H_2O_{(l)} + 3\ CO_{2(g)}$$

What would be the molarity of the H_3PO_4 solution that reacted with sufficient Na_2CO_3 to produce 54.0 grams of H_2O if the solution had a volume of 0.5 liters?

Molarity Problems continued:

3 GA 1 Sodium carbonate (Na_2CO_3) reacts with phosphoric acid (H_3PO_4) to produce sodium phosphate (Na_3PO_4), water (H_2O), and carbon dioxide gas (CO_2) according to the balanced reaction:

$$3\ Na_2CO_{3(s)} + 2\ H_3PO_{4(aq)} \longrightarrow 2\ Na_3PO_{4(aq)} + 3\ H_2O_{(l)} + 3\ CO_{2(g)}$$

What would be the molarity of the H_3PO_4 solution that reacted with sufficient Na_2CO_3 to produce 132.0 grams of CO_2 if the solution had a volume of 0.5 liters?

3 GA 2 Sodium carbonate (Na_2CO_3) reacts with phosphoric acid (H_3PO_4) to produce sodium phosphate (Na_3PO_4), water (H_2O), and carbon dioxide gas (CO_2) according to the balanced reaction:

$$3\ Na_2CO_{3(s)} + 2\ H_3PO_{4(aq)} \longrightarrow 2\ Na_3PO_{4(aq)} + 3\ H_2O_{(l)} + 3\ CO_{2(g)}$$

What would be the molarity of the H_3PO_4 solution that reacted with sufficient Na_2CO_3 to produce 264g of CO_2 if the solution had a volume of 0.5 liters?

Molarity Answers

1 Ml 116.2 g/58.1 g/mole = 2.0 moles 0.5M = 0.5 moles/liter

2.0 moles/0.5 moles/liter = 4.0 liters = 4000 mL

1 G 0.5 M = 0.5 moles/liter x 4.0 1 = 2.0 moles

2.0 moles x 58.1 grams/mole = 116.2 grams

1 Mo K 39.1 116.2 g/58.1 g/mole = 2.0 moles 2.0 moles/4.0 1 = 0.5 M

$$\begin{array}{lr} K & 39.1 \\ F & \underline{19.0} \\ & 58.1 \end{array}$$

2 MoD 3.0 M = 3.0 moles/liter x 1.5 1 = 4.5 moles

4.5 moles/2.0 liters = 2.25 M

2 MoC 2.25 M =2.25 moles/liter x 2.0 1 = 4.50 moles

4.50 moles/1.5 liters = 3.0 M

2 MoV 3.0 M = 3.0 moles/liter x 1.5 1 = 4.5 moles 4.5 moles x 1 liter/2.25 =

2.0 liters 2.0 liters - 1.5 liters = 0.5 liters .5L = 500 mL

3 WA 54 grams/18 grams/mole = 3 moles H_2O

3 moles H_2O x 2 moles H_3PO_4/3 moles H_2O = 2 moles H_3PO_4

2 moles H_3PO_4/0.5 1 = 4.0 M H_3PO_4

3 GA 1 132/grams CO_2/44 grams/mole = 3 moles CO_2

3 moles CO_2 x 2 moles H_3PO_4/3 moles CO_2 = 2 moles H_3PO_4

2 moles H_3PO_4/.5 1 = 4.0 M H_3PO_4

3 GA 2 264g CO_2/44 g/mole = 6 mole CO_2

6 mole CO_2 x 2 mole H_3PO_4/3 mole CO_2 = 4 mole H_3PO_4

4 mole H_3PO_4/.5 liter = 8 M H_3PO_4

APPENDIX M

Coding Forms

General 581
Gas Laws. 586
Stoichiometry 590
Molarity. 594

__________ Teacher __________ Success/Unsuccess __________ Interviewer
__________ Unit __________ V V Q __________ Date of Coding
__________ Treatment __________ P P R T __________ Coder
___/___/___ Problems __________ Date of Interview

Problems

PROBLEMS

__________ Correct

__________ Incorrect

Counter Number

__________ 1

__________ 2

__________ 3

Reading/Organizing

- ____ Rereads problem or parts of problem
- ____ Restates problem in own words
- ____ Performs exploratory manipulations
- ____ Uses mnemonic notation
- ____ Draws a diagram
- ____ Makes a list
- ______________________ Other

Recall

- ____ Recalls a related concept
- ____ Recalls a related problem
- ____ Uses a method of related problem

Production

- ____ Systemmatic Approach
  - ____ Approach taught
  - ____ Arithmetic algorithm
- ____ Nonsystemmatic approach
  - ____ Bright idea
  - ____ Use successive approximation
  - ____ Estimates
  - ____ Guesses/selects solution on irrelevant basis
- ____ No answer given

Strategy

- ____ Algorithmic only
- ____ Algorithmic/reasoning strategy
- ____ Random trial and error

Structural Errors

- ____ Misinterprets problem
- ____ Disregards relevant information given in problem
- ____ Disregards relevant information generated in previous steps
- ____ Misapplies relevant information generated in previous steps
- ____ Does not generate needed information from memory
- ____ Misapplies ____/____/____ Conversion
- ______________________ Other
- ______________________ Other
- ______________________ Other
- ______________________ Other

Evaluation

- ____ Routine check of manipulations
- ____ Checks that the solution satisfies conditions
- ____ Checks solution by retracing steps
- ____ Derives solution by another method
- ____ Is the result(s) reasonable?
- ____ Compares solution with general known results
- ____ Changes approach

Comments About Solution

- ____ Questions existence of solution
- ____ Questions uniqueness of solution
- ____ Questions necessity/relevence of information
- ____ Expresses uncertainty about final solution
- ____ Says he doesn't know how to solve problem
- ____ Says the problem is difficult

Executive Errors	tallies	total
Computing/arithmetic	____	____

QUESTIONS

QUESTIONS

__________ CORRECT
__________ Incorrect

Counter Number

______	1	______	5
______	2	______	6
______	3	______	7
______	4	______	8

______________ Answers question partially without prompting
______________ Needs prompting to answer successfully
______________ Answers question completely without prompting
______________ Does not answer question at all

COMMENTS

____
____
____
____

DESCRIPTION OF CODING FORM

This coding system is an adaptation of that system used by Days (1977) for problem solving strategies in mathematics and Nurrenbern (1979) in chemistry.

A. Reading/Organizing. Processes a subject uses to aid in understanding what the problem is asking or processes used to represent the problem in a form that will aid in finding a solution.

1. Rereads problem. Subject reads all or part of the problem statement more than one time or the subject reports that he is rereading.

2. Restates problem. Subject rephrases or paraphrases the problem statement in more familiar terms.

3. Performs exploratory manipulations. Subject performs some manipulations with given data without having a real plan or a clear cut reason for doing so; the subject is not testing a formulated hypothesis.

4. Uses mnemonic notation. Subject uses symbols or notation that calls to mind the variables they represent: atomic symbols, molecular formulas, chemical equation.

5. Draws a diagram. Subject draws a figure or diagram to depict the situation or conditions as stated in the problem.

6. Makes a list. Subject puts certain data into a list in order to aid him in solving the problem.

7. Other organizing procedures.

B. Recall. Processes used to recall information from memory.

8. Recalls a related concept. Subject recalls a related concept or related formula to be used in solving the problem.

9. Recalls a related problem. Subject says he remembers having or solving a problem like the present one. Subject may recall something or some activity from class.

10. Uses method of related problem. Subject applies method used to solve a previous problem to the problem being solved. Subject must say he is using the method of a related problem, e.g., "I will solve this problem the same way I solved that problem about the cow and pig."

C. Production. Processes used to carry out the plans and obtain results. Considered to be systematic if subject uses some organized mode of proceeding.

11. Approach taught. Subject uses either proportionality, diagrams, factor-label method, or analogies. This can be evident from either the comments made while solving the problem, or from the sheet the student uses, or from the questions asked.

12. Arithmetic algorithm. Subject doesn't use the method taught but uses some arithmetic algorithm, that is, some procedure that is memorized other than the one taught.

13. Bright idea. Subject, after some thought, indicates that he has just gotten an insight into the problem or an idea to follow. "Ah ha!" "Oh, I get it!" "Oh, I got an idea!" "Ah, now I see!"

14. Uses successive approximation. Subject tries one value and then uses the result obtained to get value to try next.

15. Estimates. Subject indicates that he is making an estimate or estimates of the magnitude of the solution or parts of solution.

16. Guesses/selects solution on irrelevant basis. Subject gives a solution which was derived in an arbitrary manner or based on superficial information. Wild guess. Combine numbers together without any reason to get solution.

17. Does not complete problem. Doesn't proceed enough to determine the method.

D. Strategy. Dominant sequence or sequences of processes used while attempting to solve a problem (there could be more than one strategy used in solving the same problem).

18. Algorithmic. Subject attempts to solve problem using algorithms or algorithmic forms. Does this from rote. (Wrong algorithms may be used.)

19. Algorithmic/Reasoning. Subject uses reasoning and an algorithm(s) or algorithmic form(s) to obtain solution to the problem. (Can have incorrect reasoning or arithmetic error.)

20. Random trial-and-error. Subject makes a sequence of random guesses about the solution to the problem without using any type of system or the information from previous guesses. Anything not categorized as the other two strategies.

E. Structural Errors.

21. Misinterprets problem. It is indicated in some way that the student has misread, misinterpreted, or disregarded a critical part of the problem.

22. Disregards relevant information given in problem. Subject fails to use all necessary information given in his solution attempt.

23. Disregards relevant information generated during previous steps. Subject proceeds to a solution without considering information he produced which is necessary to solve the problem. E.g., a subject may balance an equation and then ignore it in further solution steps.

24. Misapplies relevant information generated during previous steps. Subject uses information he has generated in an inappropriate way. E.g., a subject may conclude that substance X is in excess and then base further calculation on that substance instead of substance Y which would be the limiting reagent and determinor of subsequent products.

25. Does not generate needed information from memory. Student does not recall needed information such as in converting volume to moles, does not recall 22.4 1/mole.

26. Misapplies conversion factor. Student uses wrong conversion factor. E.g., in changing moles to volume, uses 6.02×10^{23} molecules. (Include one that should be used.)

27. Other structural errors.

F. Evaluation. Processes used in the checking phase of problem solving. Checking can occur after an intermediate or final result.

28. Routine check of manipulations. Subject goes back and briefly checks his operations or counting.

29. Checksthat solution satisfies the conditions. Subject substitutes the final or intermediate solution back into the problem and assures himself that all the conditions are met.

30. Checks solution by retracing steps. Subject repeats, after deriving a solution, the operations or part of the operations he performed to derive the solution.

31. Derives solution by another method. Subject, after obtaining a solution using one method, tries to use a different method or procedure to reach the solution (more formal than 28).

32. Is the result(s) reasonable? Subject compares his solution against his experience and the real world.

33. Compares solution with general known results. Subject compares his solution with what is commonly known to determine if contradictions exist.

34. Changes approach. Subject changes strategy he is using to solve the problem, e.g., did algorithmic to trial-and-error change or vice versa.

G. Comments about solution. Not considered to be processes.

35. Questions existence of solution. Subject asks if there is a solution to the problem or states that he does not think the solution exists.

36. Questions uniqueness of solution. Subject makes a direct statement referring to the possibility of more than one solution.

37. Questions necessity/relevance of information. Subject comments about some of the information given and its relevance to the situation.

38. Expresses uncertainty about final solution. Subject expresses doubt about the solution he has found.

39. Says he doesn't know how to solve the problem. This is checked even if after saying he doesn't know, the subject goes on and finds a solution.

40. Says the problem is difficult.

H. Executive Error. (To be tallied)

41. Counting/Arithmetic operations. Subject makes arithmetical error while solving problem.

I. Questions

42. Answers question partially without prompting. Prompting defined as help. Subject answers part of question on his/her own and then gets stuck. Prompting may cause answer to be completed.

43. Needs prompting to answer successfully. Subject is able to answer the question, but needs initial prompting.

44. Answers question completely without prompting. Subject needs no prompting to answer question.

45. Does not answer question at all. Subject either does not attempt question or does not answer any part of it (with or without prompting).

J. Interviewer's comments. The interviewer will record such comments as, "Student seemed nervous", "Student not sure of himself", or "Not persistent". The interviewer will also record any additional structural errors not noted on the checklist as well as any unique events which occurred such as interruptions by school announcements.

Student Number ______________

GAS LAW PROBLEMS

PROBLEM

1. 0 Doesn't get this far
1 Kelvin temperature not required
2 Fails to change to Kelvin temperature
3 Makes error in calculating Kelvin temperature
4 Converts to Kelvin temperature correctly

0 Doesn't get this far
1 Doesn't set up factor or proportion
2 Inverts a factor or sets up wrong proportion
3 Sets up problem correctly

2. 0 Doesn't get this far
1 Kelvin temperature not required
2 Fails to change to Kelvin temperature (beginning)
3 Fails to change from Kelvin temperature (end)
4 2 and 3
5 Makes error in calculating Kelvin temperature
6 Converts all Kelvin temperatures correctly
7 3 and 5
8 Other

0 Doesn't get this far
1 Doesn't set up factor or proportion
2 Disregards one of the conditions
3 Inverts a factor or sets up wrong proportion
4 2 and 3
5 Correct set up (regardless of Kelvin temperature)

3. 0 Doesn't get this far
1 Kelvin temperature not required
2 Fails to change to Kelvin temperature
3 Makes error in calculating Kelvin temperature
4 Converts to Kelvin temperature correctly

0 Doesn't get this far
1 Fails to convert moles to volume
2 Doesn't set up a factor or proportion
3 Inverts a factor or sets up wrong proportion
4 1 and 2
5 1 and 3
6 2 and 3
7 Sets up problem correctly
8 Converts to liters incorrectly
9 2 and 8

1 Confused about STP

GAS LAWS

Description of Special Coding Form

Problem 1

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Kelvin temperature not required. Problem doesn't call for conversion.

2 Fails to change to Kelvin temperature. Actually works problem or sets up problem to work without using Kelvin temperature.

3 Makes error in calculating Kelvin temperature. Uses wrong constant, subtracts instead of adding, makes math error, etc.

4 Converts to Kelvin temperature correctly. Gets correct answer.

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Doesn't set up factor or proportion. Does something else or sets up incorrectly (except for inverting, then use 2), uses some other method.

2 Inverts a factor or sets up a wrong proportion. The major error is the inversion of numbers. Otherwise it would qualify for 3. Process is correct.

3 Sets up problem correctly. Can be errors in arithmetic, etc. previous to this. Basic structure or process is correct (e.g. does problem in liters or uses wrong temperature or copies wrong number.)

Problem 2

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Kelvin temperature not required. Problem doesn't call for conversion.

2 Fails to change to Kelvin temperature (beginning). Actually works problem or sets up problem to work without using Kelvin temperature.

3 Fails to change from Kelvin temperature (end). Forgets to change back to Celsius at the end of the problem.

4 2 and 3 Both errors made.

5 Makes error in calculating Kelvin temperature. Adds wrong constant, subtracts, subtracts instead of adding, makes math error, etc. (If an error in any temperature conversion occurs, use this category.)

6 Converts all Kelvin temperatures correctly. Gets all answers correct.

7 3 and 5 Both errors occur.

8 Other Sets up first temperature correctly but doesn't proceed far enough to get to final conversion.

---

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Doesn't set up factor or proportion. Does something else or sets up incorrectly (except for inverting, then use 3), uses some other method.

2 Disregards one of the conditions. Only sets up using one of the conditions, e.g. the problem calls for temperature and pressure change, student only uses the temperature change. Use this category also if student realizes both changes but only sets up one change. (Either he can't set up both, or forgets one.)

3 Inverts a factor or sets up wrong proportion. The major error is the inversion of numbers. Otherwise it would qualify for 5. Process is correct.

4 2 and 3 Both errors made.

5 Correct set up (regardless of Kelvin temperature). Can be error in arithmetic, etc. previous to this. Basic structure or process is correct (e.g. does problem in liters or uses wrong temperature or copies wrong number.)

Problem 3

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Kelvin temperature not required. Problem doesn't call for conversion.

2 Fails to change to Kelvin temperature. Actually works problem or sets up problem to work without using Kelvin temperature.

3 Makes error in calculating Kelvin temperature. Uses wrong constant, subtracts instead of adding, makes math error, etc.

4 Converts to Kelvin temperature correctly. Gets correct answer.

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Fails to convert moles to volume. Does the problem or sets up problem without changing to volume. Also use this category if he realizes he should change but doesn't do it - forgets or doesn't know how. If he does it incorrectly, use 8.

2 Doesn't set up a factor or proportion. Does something else or sets up incorrectly (except for inverting, then use 3), uses some other method.

3 Inverts a factor or sets up wrong proportion. The major error is the inversion of numbers. Otherwise it would qualify for 7. Process is correct.

4 1 and 2 Both errors made.

5 1 and 3 Both errors made.

6 2 and 3 Both errors made.

7 Sets up problem correctly. Can be errors in arithmetic, etc. previous to this. Basic structure or process is correct (e.g. does problem in liters or uses wrong temperature or copies wrong number.)

8 Converts to liters incorrectly. Uses 6.02×10^{23} or some other incorrect procedure.

9 2 and 8 Both errors made.

---

1 Confused about STP. Doesn't associate 22.4 liters with STP, etc.

Student Number ______________

STOICHIOMETRY PROBLEMS

PROBLEM		
1.	0	Doesn't get this far
	1	Balances equation correctly
	2	Balances equation incorrectly
	3	Does not attempt to balance equation
	0	Doesn't get this far
	1	Uses equation correctly in solving problem
	2	Uses equation incorrectly in solving problem
	3	Does not use balanced equation in solving problem
2.	0	Doesn't get this far
	1	Checks to see that equation is balanced
	2	Does not check to see that equation is balanced
	0	Doesn't get this far
	1	Uses equation correctly in solving problem
	2	Uses equation incorrectly in solving problem
	3	Does not use equation in solving problem
3.	0	Doesn't get this far
	1	Checks to see that equation is balanced
	2	Does not check to see that equation is balanced
	0	Doesn't get this far
	1	Uses equation correctly for determining excess
	2	Uses equation incorrectly for determining excess
	3	Does not use equation for determining excess
	0	Doesn't get this far
	1	Uses equation correctly for determining product
	2	Uses equation incorrectly for determining product
	3	Does not use equation for determining product

STOICHIOMETRY

Description of Special Coding Form

Problem 1

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Balances equation correctly. All coefficients correct.

2 Balances equation incorrectly. Equation not entirely correct. Does not matter if incorrect coefficients are never used.

3 Does not attempt to balance equation. Uses an unbalanced equation. Does not see need for balancing equation. Student starts the problem.

---

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Uses equation correctly in solving problem. Sets up with ratios corresponding to how he balanced the equation.

2 Uses equation incorrectly in solving problem. Uses the wrong coefficients or inverts them, etc. (except for errors that occur in balancing only). Interprets coefficients as grams.

3 Doesn't use the equation in solving problem. Uses some other method or forgets about coefficients. Student starts the problem.

Problem 2

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Checks to see that equation is balanced. Overtly says he is checking the equation.

2 Does not check to see that equation is balanced. It is not apparent from tape or sheet that equation was checked.

---

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Uses equation correctly in solving problem. Sets up with ratios corresponding to those in equation.

2 Uses equation incorrectly in solving problem. Uses wrong coefficients or inverts them, etc. Interprets coefficients as grams.

3 Does not use equation in solving problem. Uses some other method or forgets about coefficients.

Problem 3

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Checks to see that equation is balanced. Overtly says he is checking the equation.

2 Does not check to see that equation is balanced. It is not apparent from tape or sheet that equation was checked.

---

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Uses equation correctly for determining excess. Uses the coefficients correctly.

2 Uses equation incorrectly for determining excess. Makes some error but still uses equation. Interprets coefficients as grams.

3 Does not use equation for determining excess. Uses some other method or forgets about coefficients. Student starts the problem.

---

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Uses equation correctly for determining product. Uses the coefficients correctly.

2 Uses the equation incorrectly for determining product. Makes some error but still uses equation. Interprets coefficients as grams.

3 Does not use equation for determining product. Uses some other method or forgets about coefficients. Student starts the problem.

Student Number ______________
593

MOLARITY PROBLEMS

PROBLEM

1.	0	Doesn't get this far	5	Uses molecular weight correctly
	1	Doesn't calculate molecular weight	6	2 and 4
	2	Calculates molecular weight incorrectly	7	2 and 5
	3	Calculates molecular weight correctly	8	3 and 4
	4	Uses molecular weight incorrectly	9	3 and 5

	0	Doesn't get this far	5	1 and 4
	1	Doesn't use definition of molarity	6	2 and 4
	2	Uses definition of molarity incorrectly	7	3 and 4
	3	Uses definition of molarity correctly	8	Both definition and mL-L change correct
	4	Error in mL-L conversion	9	Changes mL-L or vice versa correctly

2.	0	Doesn't get this far	5	Uses volume change incorrectly
	1	Realizes that volume changes	6	Works with vol.change correctly, stops
	2	Fails to use volume change	7	Doesn't get final volume
	3	1 and 2	8	Other
	4	Uses volume change correctly		

	0	Doesn't get this far	5	1 and 4
	1	Doesn't use definition of molarity	6	2 and 4
	2	Uses definition of molarity incorrectly	7	3 and 4
	3	Uses definition of molarity correctly	8	Both definition and mL-L change correct
	4	Error in mL-L conversion	9	2 and 3

3.	0	Doesn't get this far	5	Uses molecular weight correctly
	1	Doesn't calculate molecular weight	6	2 and 4
	2	Calculates molecular weight incorrectly	7	2 and 5
	3	Calculates molecular weight correctly	8	3 and 4
	4	Uses molecular weight incorrectly	9	3 and 5

	0	Doesn't get this far
	1	Realizes equation must be used
	2	Uses balanced equation correctly
	3	Uses balanced equation incorrectly
	4	Doesn't realize equation must be used

	0	Doesn't get this far
	1	Doesn't use definition of molarity
	2	Uses definition of molarity incorrectly
	3	Uses definition of molarity correctly

MOLARITY

Description of Special Coding Form

Problem 1

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Doesn't calculate molecular weight. Uses something else. Assume student gets this far.

2 Calculates molecular weight incorrectly. Makes an error in adding, uses wrong numbers. Do not mark for correct molecular weight of wrong substance.

3 Calculates molecular weight correctly. Gets correct weight even if substance is not proper one.

4 Uses molecular weight incorrectly. Makes error (other than arithmetic). May use molecular weight of wrong substance.

5 Uses molecular weight correctly. Uses molecular weight to find moles or grams. Disregard arithmetic errors.

6 2 and 4 Both errors made.

7 2 and 5

8 3 and 4

9 3 and 5 Problem correct except for arithmetic errors.

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Doesn't use definition of molarity. Uses something else. Assume student gets this far.

2 Uses definition of molarity incorrectly. Inverts terms or does something else using molarity.

3 Uses definition of molarity correctly. Process correct. Disregard arithmetic errors.

4 Error in mL - L conversion. Makes error, include decimal but not arithmetic. Fails to make the mL - L change.

5 1 and 4 Makes both errors.

6 2 and 4 Makes both errors.

7 3 and 4

8 Both definition and mL - L change correct. Problem essentially correct except for arithmetic errors.

9 Changes mL - L or vice versa correctly.

Problem 2

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Realizes that volume changes. Makes statement or infers it changes.

2 Fails to use volume change. Doesn't incorporate it in the problem - may not realize that it changes.

3 1 and 2

4 Uses volume change correctly. Correct process. Disregard arithmetic errors.

5 Uses volume change incorrectly. Inverts numbers, adds, divides, etc.

6 Works with volume change correctly and stops. Gets only part way.

7 Doesn't get final volume. Forgets last step in adding or subtracting volumes.

8 Other ______________________________

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Doesn't use definition of molarity. Uses something else. Assume student gets this far.

2 Uses definition of molarity incorrectly. Inverts terms or does something else using molarity. Should be marked if in part of problem, definition is used incorrectly.

3 Uses definition of molarity correctly. Process correct. Disregard arithmetic errors. Should be marked if in part of problem, definition is used correctly.

4 Error in mL - L converstion. Makes error, include decimal but not arithmetic. Fails to make the mL - L change.

5 1 and 4 Makes both errors.

6 2 and 4 Makes both errors.

7 3 and 4

8 Both definition and mL - L change correct.

9 2 and 3 For different parts of the problem.

Problem 3

0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Doesn't calculate molecular weight. Uses something else. Assume student gets this far.

2 Calculates molecular weight incorrectly. Makes an error in adding, uses wrong numbers. Do not mark for correct molecular weight of wrong substance.

3 Calculates molecular weight correctly. Gets correct weight even if substance is not proper one.

4 Uses molecular weight incorrectly. Makes error (other than arithmetic). May use molecular weight of wrong substance.

5 Uses molecular weight correctly. Uses molecular weight to find moles or grams. Disregard arithmetic errors.

6 2 and 4 Both errors made.

7 2 and 5

8 3 and 4

9 3 and 5 Problem correct except for arithmetic errors.

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0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Realizes equation must be used. Makes a statement that the equation is required.

2 Uses balanced equation correctly. Uses correct ratios.

3 Uses balanced equation incorrectly. Uses wrong ratios, wrong substances, grams instead of moles, etc.

4 Doesn't realize equation must be used. Works problem without reference to equation.

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0 Doesn't get this far. Says he doesn't know how to do problem. Just doesn't begin.

1 Doesn't use definition of molarity. Uses something else. Assume student gets this far.

2 Uses definition of molarity incorrectly. Inverts terms or does something else using molarity.

3 Uses definition of molarity correctly. Process correct. Disregard arithmetic errors.

APPENDIX N

Instructional Units and Tests

Under Separate Cover